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THE JOINT CRUISE MISSILES PROJECT:
AN ACQUISITION HISTORY--APPENDIXES

E. H. Conrow, G. K. Smith, A. A. Barbour

August 1982

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The Joint Cruise Missiles Project Office

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SANTA MONICA, CA 90406

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Provides additional details of project organization and management procedures to the main report, "The Joint Cruise Missiles Project: An Acquisition History," Rand R-3039, August 1982. These appendixes include: Joint Cruise Missiles Project Office Evolution; DMA/JCMPO Interaction; Cruise Missile Test Program; ALCM Competitive Flyoff; Sustainer Engine Production Competition; Production; Cruise Missile Land-Attack Guidance System; Warranties; and Program Costs.

A RAND NOTE

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PREFACE

An important part of the process of improving acquisition management methods is the accumulation of experience from current or recently completed programs, especially if those programs involved unusual situations or innovative management techniques. This Note documents the experience to date of one such program, the Joint Cruise Missiles Project, a designated joint Navy/Air Force system acquisition effort. The research, sponsored by the Joint Cruise Missiles Project Office, examines the organization and management methods which that office used from its formation in 1977 until mid-1982, the cutoff date for the research reported here.

Although the 1977 DSARC II decision memorandum that initiated the Joint Cruise Missiles Project also directed that advanced cruise missile technology programs be conducted, those programs are not discussed here.

This Note contains material that supplements the research findings reported in Rand Report R-3039-JCMPO, *The Joint Cruise Missiles Project: An Acquisition History*, by E. H. Conrow, G. K. Smith, and A. A. Barbour. This supplementary material is organized and presented as if it were a part of that parent report; it is published separately to provide documents of more manageable size and weight, and with the expectation that only a fraction of those reading the main report will want to delve into the additional details presented here.

The sections of the Note are organized according to subject matter and are presented in the order in which the topics are raised in the main report. Because of the somewhat specialized nature of the information contained herein, it is assumed that the reader not only has access to R-3039-JCMPO, but also has some general knowledge of cruise missile technology, acquisition practice, and the associated organizations.

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GLOSSARY

ABL	Armored box launcher
ACE	Alternate cruise engine
AFSC	Air Force Systems Command
AFTEC	Air Force Test and Evaluation Center
AGL	Above ground level
AGM	Air to ground missile
ALCM	Air launched cruise missile
ALSM	Air launched strategic missile
ASD	Aeronautical Systems Division of AFSC
AUR	All-up round
BAC	Boeing Aircraft Company
BAFO	Best and final offer
CE	Current estimate
COMOPTEVFOR	Commander, Operational Test and Evaluation Forces
CNM	Chief of Naval Material Command
CNO	Chief of Naval Operations
CMGS	Cruise missile guidance set
CT&E	Contractor test and evaluation
DE	Development estimate
DLMS	Digital landmass system
DMA	Defense Mapping Agency
DOD	Department of Defense
DOE	Department of Energy
DSARC	Defense Systems Acquisition Review Council
DSMAC	Digital scene matching area correlator
DT	Development testing
DT&E	Development, test, and evaluation
DTED	Digital terrain elevation data
EXCOM	Executive Committee
FFAT	Final factory acceptance tests
FOT&E	Follow-on test and evaluation
GAO	General accounting office
GD/C	General Dynamics Corporation, Convair Division
GFE	Government furnished equipment
GLCM	Ground launched cruise missile
GFP	Government furnished property
ILS	Integrated logistic support
INE	Inertial navigation element
INS	Inertial navigation system
IOC	Initial operational capability date
IOT&E	Initial operational test and evalutaion

IR	Infrared
IWCS	Integrated weapon control system
JCCB	Joint configuration control board
JCMPO	Joint Cruise Missiles Project Office
JEPO	Joint Engine Project Office
JSTPS	Joint Strategic Target Planning Staff
LAC	Land-attack conventional (missile)
LCC	Launch control center
LG&CS	Guidance and Control Systems Division of Litton Industries
LOP	Level of performance
LSL	Litton Systems Limited
MDAC	McDonnell Douglas Astronautics Company
MOA	Memorandum of agreement
MRRT	Missile readiness recertification tests
MRT	Missile readiness tests
MRASM	Medium range air to surface missile
MIPR	Military interdepartmental purchase request
MSL	Mean sea level
MTBF	Mean time between failure
MYP	Multi-year procurement
NAVAIR	Naval Air Systems Command
NAVMAT	Naval Material Command
OAS	Offensive avionics system (B-52)
O&S	Operations and support
OSD	Office of the Secretary of Defense
OT	Operational testing
OTH	Over the horizon
OTL	Operational test launch
OT&E	Operational test and evaluation
PA&E	Program Analysis and Evaluation (OASD)
PAT&E	Product acceptance test and evaluation
PCC	Probability of correct correlation
PI/DE	Passive identification/detection
PPP	Pre-production prototype
PPPI	Preplanned product improvement
PRR	Production readiness review
Q/RST	Qualification/reliability sampling tests
RAD	Requirements analysis document
RDT&E	Research, development, test and evaluation
RD&L	Research, development, and logistics
REM	Recovery exercise module
RE&S	Research, engineering, and systems
RIW	Reliability improvement warranty
RFP	Request for proposal

RMUC	Reference memory unit and computer
SAC	Strategic Air Command
SAR	Selected Acquisition Report
SE	Support equipment
SFC	Specific fuel consumption
SLCM	Submarine launched cruise missile (original meaning)
	Sea launched cruise missile (current meaning)
SK	Singer Company, Kearfott Division
SMAC	Scene matching area correlator
SRAM	Short range attack missile
SSA	Source selection authority
SSAC	Source selection advisory committee
SSEB	Source selection evaluation board
SSP	Source selection plan
TAAM	Tomahawk airfield attack missile
TASM	Tomahawk anti-ship missile
TATE	Tooling and test equipment
TCAE	Teledyne Corporation, Continental Aircraft Engine Division
TDP	Technical data package
TEL	Transporter erector launcher
T&E	Test and evaluation
TEMP	Test and evaluation master plan
TERCOM	Terrain contour matching
UFC	Unit flyaway cost
USDR&E	Undersecretary of Defense for Research and Engineering
VLS	Vertical launch system
VOD	Vertical obstruction data
WIC	Williams International Corporation
WPAFB	Wright Patterson Air Force Base
WVT	Warranty verification tests

Appendix A
JOINT CRUISE MISSILES PROJECT OFFICE EVOLUTION

CREATION OF THE JCMPO

An initial proposed organizational structure for the Joint Cruise Missiles Project Office (JCMPO) was prepared in January 1977 in response to the DSARC II decision memorandum (Fig. A.1). At that time it was envisioned that the JCMPO would be a part of the Naval Air Systems Command (NAVAIR), under the Chief of Naval Material Command (CNM), in part because the existing Navy project office was under the jurisdiction of NAVAIR. Air Force interaction with the JCMPO would include coordination from the Air Launched Strategic Missile (ALSM) Program Office at Wright Patterson Air Force Base, Ohio (WPAFB). That office, a part of the Aeronautical Systems Division (ASD) under the Air Force Systems Command (AFSC), had been the Air Force focal point for the Air Launched Cruise Missile (ALCM) program. In addition, there would be reporting and coordination interaction between the JCMPO and ASD to ensure that Air Force objectives would be met on the ALCM and Ground Launched Cruise Missile (GLCM) programs. Although the Navy would be the Excutive Service for the cruise missile project, the Air Force would provide functioning support and coordination to the ALCM and GLCM Project Offices through the ALSM Program Office at WPAFB.

Following the DSARC II decision memorandum of January 14, 1977 the two services exchanged a series of Air Force and Navy sponsored JCMPO draft charters. On February 7, 1977, Admiral H. Shear, the Vice Chief of Naval Operations, provided guidelines for the execution of the taskings given in the DSARC II decision memorandum as they applied to the Navy. He specified that OP-02, as the Tomahawk project sponsor, and OP-090, Director of Navy Program Planning, should provide Navy representation. In addition, he specified that the Navy Project Manager[1] (Captain Walter M. Locke) was to have clear lines of authority

[1] Beginning on April 12, 1978, the JCMPO manager and deputy manager titles were changed to Director and Deputy Director. The latter titles are used throughout the remainder of this Note.

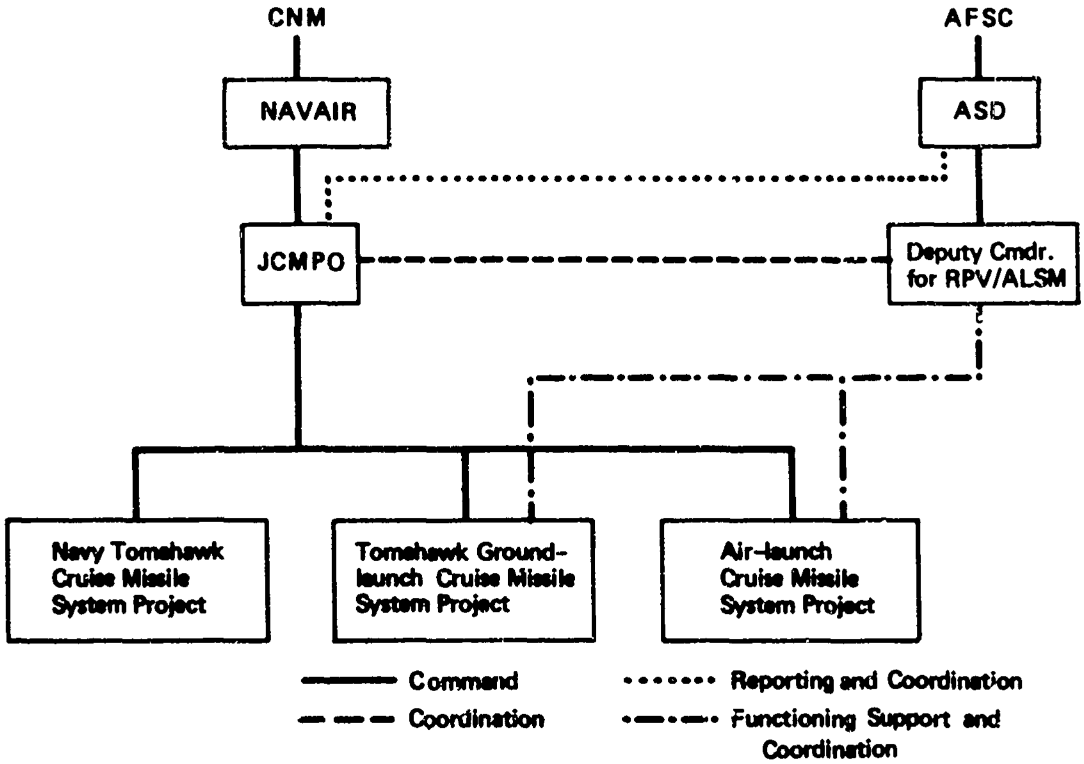

Fig. A.1 -- Proposed January, 1977, JCMPO Organizational Structure

to manage effectively, the project office should be adequately staffed and located within the Washington, D.C. area, and that an agreement was to be drafted with the Air Force specifying the funding procedures to be used in the joint project. It was further specified that this agreement should adhere to the basic principle that the user services will be responsible for obtaining the necessary funding through their normal budget processes to support their respective programs. Principal issues remaining at that time for the formulation of JCMPO included: the physical location of the ALCM and GLCM offices, the budget control authority of the joint project manager, the lead service for the engine and guidance subsystems procurement, the mechanism for consolidation of service funding, and other organizational and personnel related items.

A plan for establishing the JCMPO was presented at the Chief of Naval Operations' Executive Board meeting on February 25, 1977. The initial JCMPO organizational structure was approved at that time,

priority given to filling the necessary Navy billets, and a recommendation made that the Navy vigorously pursue becoming the lead service for engine procurement. The Navy was the acknowledged leader in the cruise missile guidance system development, but the Air Force to that time had been managing the development of the F107 engine and consequently claimed that it should be the lead service for engine procurement.

The Navy proposed that budget execution control be an essential element of the joint cruise missile management plan and that separate Air Force and Navy program elements for cruise missile systems projects would be retained under Navy financial control. In addition, funding should be consolidated under a single service (the Navy) as directed in the DSARC II decision memorandum, through the use of a Military Interdepartmental Purchase Request (MIPR), and that the Air Force should transfer all funds in their program elements to the Navy at the departmental level.

On March 2, 1977, Dr. John Martin, Acting Secretary of the Air Force, wrote to Mr. H. Tyler Marcy, Assistant Secretary of the Navy for R&D, agreeing that the JCMPO should be under Navy financial control, although separate Air Force and Navy program elements for cruise missile systems projects should be retained. Air Force funds cited directly on contracts for missile components were to be transferred to the JCMPO, and agreement was reached with the Navy on the program and budget formulation and coordination responsibility of JCMPO. Dr. Martin also stated that the Air Force should be responsible for development of the common engine and that Boeing, the ALCM contractor, should retain appropriate influence concerning the ALCM autopilot, flight controls, and navigational guidance software.

In a March 3, 1977, response to the Martin memorandum, Captain Locke emphasized that proper financial control must be exercised in an expeditious manner by the joint cruise missile project manager and that full control of all funds was necessary as they were released by the OSD Comptroller. The argument against using the MIPR procedure was that if the Air Force funds for cruise missiles were allowed to filter down to ASD, the various levels of command would be offered the opportunity to delay and/or micro manage, which would tend to pre-empt the prerogatives

and control of the JCMPO Director. On March 4, 1977, these points were conveyed to Dr. Martin by Mr. Marcy, who acknowledged the Air Force case with respect to engine development and stated that to ensure commonality, issues pertaining to ALCM-unique guidance system hardware and software should be decided case by case.

In a memorandum to Dr. Martin on March 9, 1977, Mr. Marcy changed the Navy position on the common engine development from wanting responsibility for coordinating engine development, to developing a workable arrangement with the Air Force on this matter. In a replying memorandum on March 15, 1977, Dr. Martin acknowledged the Navy deferral in the common engine development and suggested that because JCMPO provided a mechanism to achieve commonality (where practical), it should move ahead with Air Force developed guidance specifications (at least for the ALCM). Dr. Martin disagreed, however, with the Navy position on when and at what level funds should be transferred, and with the transfer of current year unobligated funds to the JCMPO. The Air Force position was that it must retain a degree of control at the departmental level, but that as the JCMPO Director would be held summarily accountable as well, the JCMPO should be under Navy financial control. In addition, the Air Force preferred to release funds periodically to the JCMPO as progress of the programs dictated.

Following additional debate between the Air Force and Navy on issues including common engine development and management and the financial operations of JCMPO, Mr. Robert N. Parker, the Acting Director of Defense Research and Engineering, issued a memorandum on March 25, 1977, directing that the JCMPO Director (Navy) and Deputy Director (Air Force) would be responsible for the overall cruise missile systems development process, and that "Maximum commonality on subsystems, components and software, joint testing and evaluation, and quantity buy of common components will be carefully planned and implemented without degrading individual system performances." Mr. Parker further specified that upon receipt from OSD, the Air Force was to transfer its entire program element fund for the ALCM and GLCM, and the Navy its entire fund for the Sea Launched Cruise Missile (SLCM), to the JCMPO, and that the Air Force and Navy were designated the lead services for engine and guidance systems, respectively, for all cruise missiles under the

jurisdiction of the JCMPO. In addition, an Air Force Deputy Project Manager for (turbofan) Engine Development would be assigned and his office located at ASD, while the office of the GLCM Deputy Project Manager and his staff would be collocated with the SLCM project office to ensure close coordination.

Although the Air Force and Navy were willing to accept most of these points, the Air Force objected to the collocation of the GLCM project with the SLCM project in Washington, D.C., citing a February 1977 informal agreement between the Commanders of ASD and NAVAIR. In that agreement, the GLCM Project Manager and supporting functional specialists, as required, would be placed on temporary duty in Washington, and a decision on continuation of that on-site working group, and on enlarging it to a System Project Office, would be held in abeyance until later (no more than 180 days). The rationale was that if an interface need could be satisfied with a GLCM Liason Office in Washington, it would be considered advantageous from an Air Force point of view to have the GLCM Project Office at ASD so that the development of other major items (i.e., mission planning function) could successfully proceed. Whether the GLCM project should be permanently or temporarily collocated with the Navy SLCM may seem a minor point, but it remained an open issue for some time and had a detrimental effect upon early GLCM staffing and cooperation by some elements within the Air Force.

Before May 1977 the Air Force and Navy had agreed that an Air Force F107 engine project director would be added to the JCMPO organization and that a coordination interaction would exist between the deputy directors for the ALSM and Propulsion program offices at WPAFB.

In a June 28, 1977, memorandum to the Commander of NAVAIR, Captain Locke stated that the Charter for the JCMPO had been in the coordination cycle between representatives of ASD and the JCMPO for several months and that they had reached an impasse on two issues. The first was related to the Navy being established as the Executive versus the Lead Service for cruise missiles, and the conflicting views as to the authority and responsibility that would go with each status. The second dealt again with the location of the Air Force GLCM Project Office. Captain Locke stated that the lack of a signed charter "impacted the

initial operation of the Joint Program," by slowing personnel resources and somewhat fragmenting the lines of authority. Although the Commander, NAVAIR, fowarded a draft Charter to the CNM and to the ASD Commander on June 30, 1977, with recommendation for early approval, the Air Force later returned it unsigned as a result of their estimate of the effect of the B-1 production cancellation (announced that day).

On August 7, 1977, Lt. General H. Sylvester, the ASD Commander, advised the Commander, NAVAIR that "a number of events have recently occurred which preclude approving the Charter until the implications are thoroughly understood." Those events pertained to the Air Force establishment of a Strategic Weapons System Program Office at ASD, and the OSD-announced intention of conducting an ALCM flyoff between the Air Force AGM-86B and the Navy AGM-109.

On September 30, 1977, Dr. William Perry, Director of Defense Research and Engineering, issued a memorandum to the Secretaries of the Air Force and Navy directing that a formal ALCM competition take place between the AGM-86B, designed by Boeing, and the AGM-109, designed by the Convair Division of General Dynamics (GD/C), to determine which missile would be deployed on the B-52. At that time, four separate cruise missiles were to be under JCMPO management once its charter had been approved by the Air Force and Navy. These included the AGM-86B candidate ALCM (derived from the AGM-86A, or ALCM-A), the AGM-109 candidate ALCM (derived from the SLCM), the GLCM, and the SLCM (which included anti-ship and nuclear armed land-attack variants). Dr. Perry also specified the authority that JCMPO would have and the structure it should follow, not only for the ALCM flyoff, but for the GLCM and SLCM programs as well. Simply stated, as the ALCM flyoff was elevated to a matter "of highest national priority," OSD would not allow service infighting to continue to impede the creation of the JCMPO or its subsequent operation.

The September 30, 1977, memorandum also emphasized the importance of component commonality between the two candidate ALCMs and the GLCM and SLCM, and directed that program management responsibility was to remain in a joint Air Force-Navy project office (JCMPO) until the ALCM competition was completed, a design selected, and a DSARC III had approved production of the ALCM. At that time the GLCM program

management responsibilities would be assigned to the Air Force and SCLM to the Navy. Because of the high priority of the ALCM program and its early desired operational date, Dr. Perry stated that the present joint project management team should be retained, but that staff and responsibility would be added to create operating flexibility in the project office. Specifically, the project office would have its own contracting and systems engineering staff and be patterned after the successful Navy Fleet Ballistic Missile Program Office. The recommended JCMPO organization is shown in Fig. A.2.[2] Additionally, all deputy program managers were to be collocated with the JCMPO, which would report directly to the CNM for its logistics, manpower, and administrative support. Finally, it was specified that the cruise missile project should have a BRICK BAT (DX) priority at the earliest possible date.

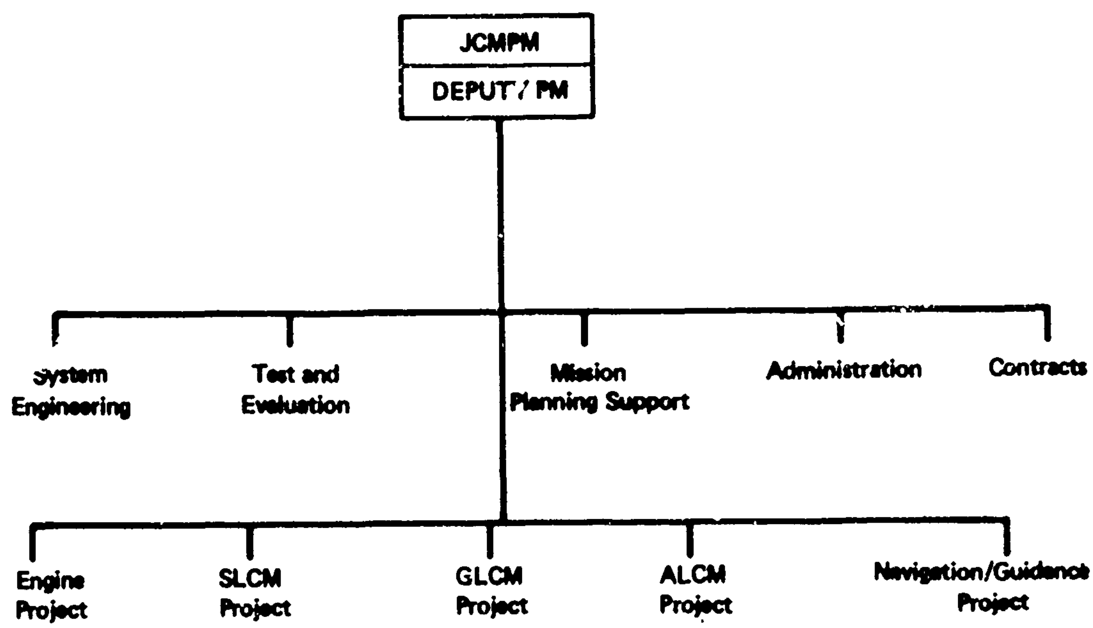

Fig. A.2 -- September, 1977 Designated JCMPO Organizational Structure

The funding procedures used called for the Air Force and Navy to allocate their entire program element fund for cruise missiles directly to the JCMPO upon receipt from OSD. To further monitor the progress of the ALCM flyoff and other cruise missile variants, an Executive Committee (EXCOM) was established to provide programmatic and fiscal direction.[3] Finally, Dr. Perry specified that the JCMPO organization was effective on September 30, 1977, and charged the Secretaries of the Air Force and Navy to "provide the support necessary for an efficient JCMPO which will give the Nation by 1980 an outstanding new weapon system (ALCM) at minimum acquisition cost."

Also on September 30, 1977, NAVMAT Notice 5430 from the CNM was issued regarding the JCMPO. It designated Captain Walter M. Locke as the project director and established the JCMPO as a CNM-level designated project office effective that date.

At the first EXCOM meeting (October 21, 1977) discussions were held regarding the role of the EXCOM in the cruise missile project and the status of actions given in NAVMAT Notice 5430 in support of the formation of the JCMPO. It was decided that EXCOM meetings would be held quarterly, with special meetings called by the chairman. In addition, the EXCOM was not to be a voting group; rather its purpose would be to review and discuss in an attempt to establish a consensus. In the absense of a consensus, the Under Secretary of Defense for Research and Engineering (USDR&E)[4] would act as required and report dissenting opinions to the Secretary of Defense along with recommendations for action. Normal channels would remain open to the Services to express dissent. Another feature of the EXCOM was that it would provide a forum for an expeditious review of problem areas. In

[2] The JCMPO soon added a Business and Acquisition Office, but otherwise substantially adopted the suggested organization.

[3] The members included the Director of Defense Research and Engineering (who chaired the committee), the Assistant Secretary of the Navy (RE&S), the Assistant Secretary of the Air Force (RD&L), the Vice Chief of Naval Operations, the Air Force Vice Chief of Staff, the Assistant Secretary of Defense (PA&E), and the Assistant Secretary of Defense (Comptroller). After the first meeting, the Chief of Naval Operations and the Commander, Air Force Systems Command, were added as permanent members.

[4] Previously identified as the Director of Defense Research and Engineering, the title of the office was changed on October 21, 1977.

addition, through its high level OSD and Service membership, and the use of action item assignments, EXCOM interaction with JCMPO could potentially minimize program cost and schedule risk.

A discussion was also held during that meeting of open action items from NAVMAT Notice 5430, including ones pertaining to the Charter and Operating Agreements. It was noted that the Charter was directed toward *what* was to be accomplished rather than *how* it would be accomplished. Operating agreements between the Air Force and Navy were to be considered separately from the charter and used to resolve inter-Service issues (e.g., the extent of JCMPO system responsibility for the cruise missile).

On February 8, 1978, a revised notice (NAVMAT Instruction 5430.39) was issued establishing the Joint Cruise Missiles Project as a designated joint project under the administrative direction of the CNM; it provided a charter specifying the project scope, operating relationships, organization, and resources for the JCMPO and delineated the authority and responsibility of the Project Director within the Naval Material Command. The Project Director was to be a Navy Rear Admiral and Deputy Project Director was to be an Air Force Colonel. Captain Locke was promoted to Rear Admiral in March 1978.

By early 1978, the JCMPO organization had evolved into an arrangement that was close to that given in Dr. Perry's September 30, 1977 memorandum (Fig. A.3). The JCMPO reported: (a) directly to CNM for administrative matters and for execution of the Navy program management responsibilities; (b) through a coordination link to AFSC for reporting Air Force program management responsibilities; and (c) through an advisory link to the EXCOM. In April 1978 the link to the AFSC was changed from "reporting and coordination" to "command" to more formally recognize Air Force program control, and that arrangement remains to date.

The resulting organizational structure appears to put the JCMPO Director in the position of reporting to three different authorities. Although Admiral Locke was clearly *responsible* for management of the project, the exact distribution of *authority* is not well documented.[5] The EXCOM was officially referred to as an "advisory body," but it seems

[3] This troublesome issue is addressed obliquely in the formal regulations and manuals on joint program management. For example, the

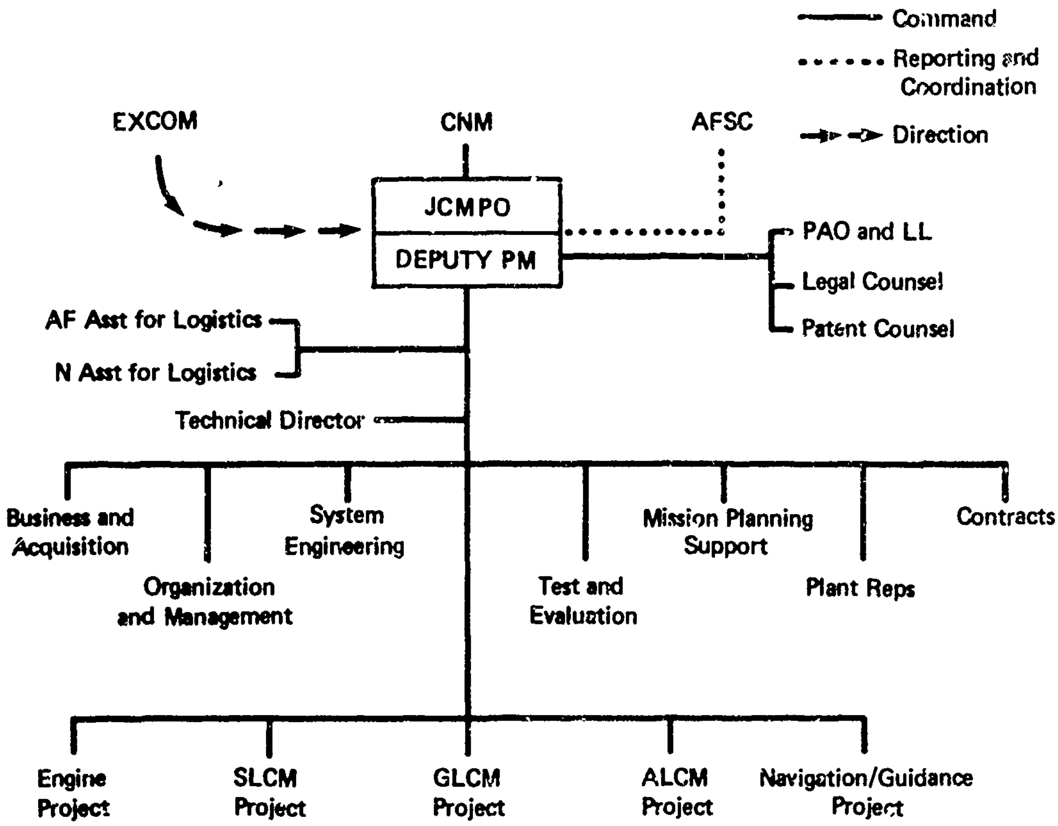

Fig. A.3 -- January, 1978, JCMPO Organizational Structure

clear that Dr. Perry, EXCOM chairman and USDR&E, acted as the senior authority whenever it became necessary to resolve disputes between the services. A successful joint program Director must prevent most issues from escalating to the point where EXCOM authority must be invoked, but again the details of how that was accomplished in the JCMPO are not well documented. A few examples are noted elsewhere in this appendix.

One important fact not apparent from this organizational structure is that the "Engine Project" consisted almost entirely of the Air Force Joint Engine Project Office (JEPO) located at Wright-Patterson AFB. The head of that office (an Air Force Colonel) and the deputy head (a Navy

Joint Logistics Commanders Guide for the Managment of Joint Service Programs (Defense Systems Management College, 1980), contains the phrase "Typically, the ...USDRE writes a memorandum designating one Service the Executive, or Lead, Service and directing it to charter a joint program....Less formal *but no less compelling* direction is given to the Services during program or budget reviews." (Emphasis added)

Commander) alternated between WPAFB and the JCMPO, with the entire technical staff located at WPAFB and contracting and business functions conducted in the JCMPO. That was in contrast to the Navigation/Guidance Project at the JCMPO, which was primarily staffed by Navy personnel and utilized the Applied Physics Laboratory and several Navy facilities for technical support.

During the following two and a half years only minor changes were made in the JCMPO organizational structure. In November 1978 a Mission Analysis group was added to assist in the cruise missile survivability test program; in January 1979 the Mission Planning Support office was deleted; and in April 1979 the separate Air Force and Navy Assistants for Logistics were combined into a single Deputy for Logistics. Near the end of 1979, the Contracts Office was placed under the jurisdiction of the Business and Acquisition Office. Otherwise, the JCMPO organizational structure remained unchanged until the middle of 1980.

ALCM MANAGEMENT TRANSITION

The next major event that affected JCMPO organization was the transfer of ALCM project management to the Air Force. The transfer had been anticipated in Dr. Perry's September 1977 memorandum mandating the ALCM flyoff. A second memorandum from Dr. Perry (October 17, 1979) directed that the ALCM transition to the Air Force take place in an orderly process at the end of Follow-On Test and Evaluation following DSARC III to ensure continued commonality with other cruise missile programs and that key personnel and expertise were available for the ALCM program.

Cruise missile transition plans were under development by both the Air Force and JCMPO approximately four months before the ALCM DSARC III, which was held on April 17, 1980. The Air Force approach was basically to decentralize the JCMPO. In addition to removing the ALCM, the Air Force proposed to remove the GLCM, and to control the ALCM systems integration within their infrastructure and cruise missile commonality through a Joint Configuration Control Board (JCCB). In addition, the Air Force, with the largest approved program buy of the two services at

that time (ALCM/GLCM of 3942, SLCM of 502), proposed to control the common cruise missile subsystems by being the lead service. The Air Force further argued that because the ALCM was the lead production buy, it should drive commonality with the other cruise missile variants. The Navy (and JCMPO) counter-position on these items was that the JCMPO should be maintained for centralized management of the GLCM, SLCM, and common subsystems, while the ALCM could be split off to the Air Force after DSARC III in accordance with the October 17, 1979, USDR&E memorandum. The JCMPO proposed maintaining, up to at least to six months before the GLCM/SLCM DSARC III, centralized control (contracting and system configuration control) of all cruise missile common subsystems, including the engine, guidance, mission planning, and weapon control system.

The JCMPO argument to retain management of the cruise missile program was based on what it viewed to be costly and disruptive results of any major decentralization effort. It viewed such a move as potentially causing a loss of the synergistic effect and cost savings from integrating both Services' needs and requirements; government expertise and know-how that was centrally located in one project office; management commitment to innovative measures that had previously been demonstrated; a successful model for future joint program endeavors; and a centralized organization for improvements, alternative uses, and future developments involving cruise missiles. To provide better Service interaction, the JCMPO proposed that the Services should be responsible for system integration of cruise missiles to the candidate launch platform, requirements for development, deployment, training and any launch platform modifications for each cruise missile variant, and site activation.

At the EXCOM meeting on January 23, 1980, both the Air Force and JCMPO made preliminary presentations on their management transition plans. The Air Force believed the dominant issues involved total weapon system integration, nuclear certification, and activation/deployment and that these could best be addressed by centralized integration within the Air Force infrastructure and management of common subsystems. The Air Force was, however, sensitive to Navy interests in the common subsystems, and was prepared to serve them through the use of a JCCB.

The Air Force recommended that the transition process consist of a joint effort during April-September 1980 with the shift in ALCM funding and contracting lead responsibility from the JCMPO to the Air Force occuring in May 1980 to facilitate integration and assure a closely coordinated and timely process toward the scheduled tests. The Air Force stressed the importance of resolving the ALCM transition, because production contracts would soon be executed, and to ensure meeting deployment schedule milestones.

The JCMPO recommended that the GLCM and SLCM be considered separately from the ALCM in terms of the time of their transition from the JCMPO to the Services, because considerably more R&D remained for those systems, and in addition their development stressed commonality/identicality as a goal. The JCMPO position with regard to the ALCM transition was that it should occur no earlier than September 1980 and as late as March 1981, because air vehicle developmental data would have to be evaluated for the winning ALCM contractor's design. The Navy position on this point was that a reasonable transition point was at the change of the fiscal year (October 1, 1980).

At the conclusion of the January EXCOM meeting, the OSD position was that the ALCM should be split out and returned to the Air Force and that it was desirable to quickly define a plan for doing so. Furthermore, the JCMPO should continue indefinitely as manager of the GLCM, SLCM, and other joint projects (as appropriate), that any transition plan should reflect the remaining missile development needs, and that the ALCM transition should not aggravate existing problems. A special EXCOM was scheduled to receive the Program Director's assessment of the ALCM transition, a critique of the Air Force approach, and the JCMPO transition plan.

In a January 28, 1980, letter to Dr. Perry, the Secretary of the Air Force urged OSD to transfer the ALCM at DSARC III, arguing that the combined B-52/ALCM weapons system was the primary consideration, not the ALCM alone. At the special EXCOM held on February 26, 1980, the Air Force recommended that the ALCM (including the missile, guidance, engine, and strategic mission planning function) be transferred at DSARC III, the contracts function transferred within 30 days, that a JCCB be established immediately, and that the transition process be completed by

October 1, 1980. The JCMPO recommended that the program management for ALCM production be transferred at DSARC III, but that the final ALCM transition not occur until the conclusion of the ALCM (missile) development and operational test phases. It also recommended that the USDR&E promulgate the decision that JCMPO management of the GLCM and SLCM should continue through each missile's initial operational capability (IOC) date, that JCMPO manage technical direction of the engine, guidance, and mission planning center through the GLCM IOC, and that the commonality for all cruise missiles be continued by using the JCMPO JCCB as a mechanism for configuration control.

Dr. Perry issued a memorandum on the cruise missile management transfer on March 7, 1980. It stated that a formal transfer of management responsibility for the ALCM program to the Air Force would take place at the DSARC III, with the transfer taking place as quickly thereafter as possible without disrupting ongoing activities, and that the ALCM contract responsibility would be transferred within 30 days after the DSARC III to the Air Force from JCMPO. Although the common subsystems had reached a high level of maturity such that either organization could provide them, Dr. Perry stated:

> "The advantages to the government in procuring them via the current business management approach and with the current team outweighs benefits that could be obtained by changing management; therefore, the Joint Office should retain these responsibilities, supplying needed subsystems to both Air Force and Navy programs. Through separate subsystem agreements between the JCMPO and the ALCM program manager, the JCMPO will be responsive to the ALCM program needs as well as the needs of other cruise missile programs."

He also announced the establishment of a cruise missile configuration control board to resolve standardization and configuration issues that might occur.

With regard to the GLCM and SLCM programs, Dr. Perry wrote that the "appropriate time for transfer should be no earlier than the GLCM DSARC III review" and that a phased and orderly transition process was expected at that time. In addition, he stated that the EXCOM would continue to "provide policy guidance to the JCMPO and to provide a mechanism for resolving major interface issues among the various cruise

missile programs." Although the ALCM program manager was to continue briefing the EXCOM, he would receive his management direction solely from the Air Force beyond the DSARC III date. Finally, Dr. Perry directed the initiation of the medium-range air-to-surface missile (MRASM) program to be based upon the existing (GD/C) AGM-109 cruise missile design, and assigned management responsibility for it to the JCMPO.

JCMPO MANAGEMENT EVOLUTION AFTER ALCM TRANSFER

In addition to the organizational changes that occurred in mid-1980 (described in R-3039-JCMPO), some additional changes in the organization occurred in March 1981 when the Weapons Control Project was formed and assigned the Command and Launch subgroup formerly under Command Support Programs. Similarly, the Command Support Project Directorate was created and staffed mainly with personnel from the Mission Support group formerly under Command Support Programs. The Command Support Project Directorate was organized into separate groups for Theater Mission Planning and Over The Horizon & Communications.

Another reorganization occurred on November 16, 1981, as shown in Fig. A.4. The Weapons Control Project was deleted, and the previous Production Division, the Configuration and Data Management Division, and the Product Assurance Directorate were merged into the new Product Assurance and Manufacturing Control Directorate. The change was a result of the SLCM nearing production, and the fact that it shared major common subsystems with the ALCM (already in production).

An evaluation of the JCMPO (with emphasis on the submarine-launched SLCM program) was performed early in 1981 by Rear Admiral S. G. Catola et al., in response to a concern over flight test failures. The review found that the reorganization of the JCMPO after the ALCM transitioned to the Air Force was sound, although its timing "was unfortunate as both contractors and government had understandable difficulties in adapting to the major changes at a critical point in program development and transition to production." The Review Team also found that the overall manning of the JCMPO was equal to or better than most (Navy) Project Offices, although it said that the Configuration Management Office did "not appear equal in manning, personnel, funding, or charter, to the

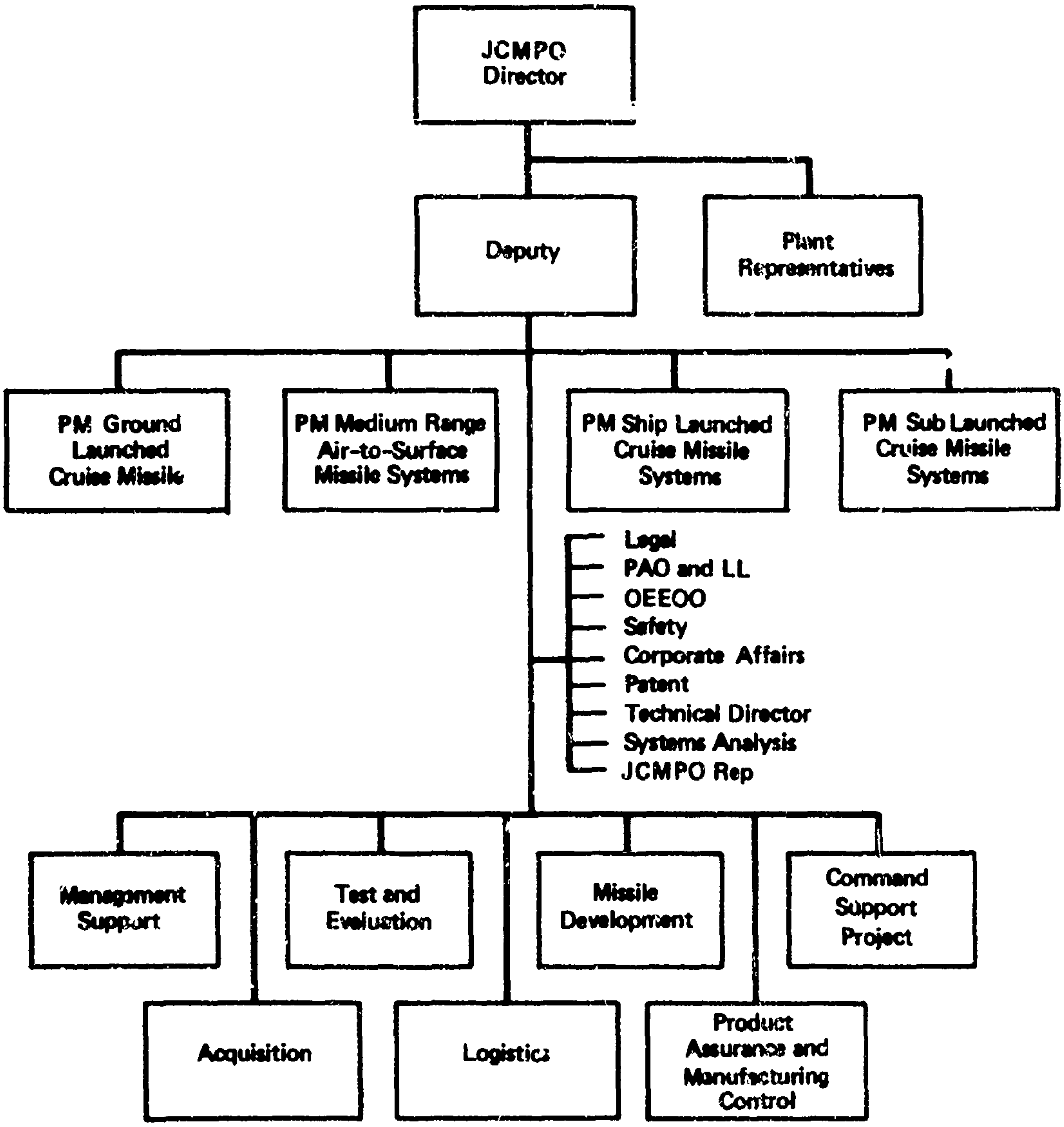

Fig. A.4 -- November 1981 JCMPO organizational structure

substantial task of control" (at that time). The study also concluded that the Business and Acquisition Office "appears to do a very good job in a particularly difficult area" and that the Production Division of the Acquisition Directorate would be more appropriate as a separate directorate with interaction with the Product Assurance Directorate. (As previously mentioned, the Production Division was added to the Product Assurance and Manufacturing Control Directorate on November 16, 1981.)

Project Office Staffing

Staff size for the JCMPO, excluding offsite personnel, is summarized in Fig. A.5 for the period from late 1977 to 1980. After the initial buildup in 1978, total staff remained in the neighborhood of

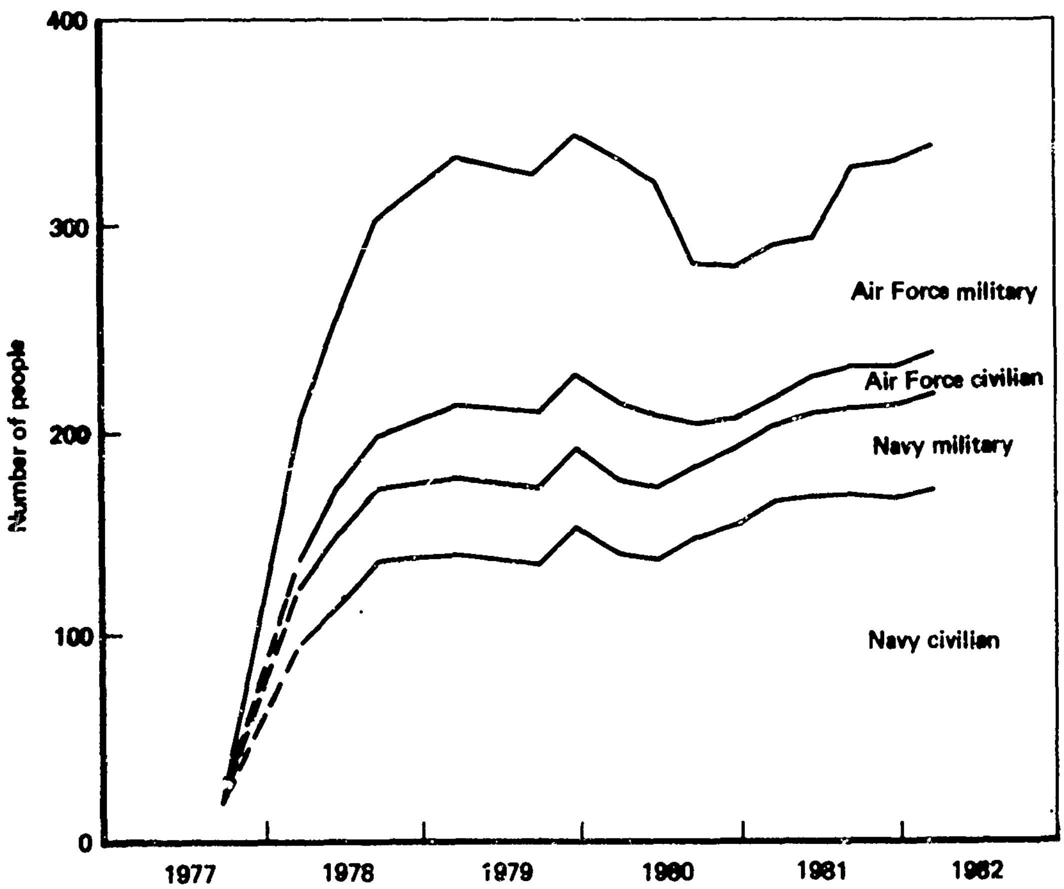

Fig. A.5 -- JCMPO Staff Size During 1977-1981

300, decreasing somewhat from mid-1980 when the ALCM program was transferred to the Air Force, until early in 1981 when the Air Force began to support the GLCM effort within the JCMPO. Throughout that period the Air Force maintained a staff of more than 100 officers and 30 to 40 civilians; the large proportion of uniformed staff was largely because it was more practical to reassign officers than to move civilians from the Air Force development center at WPAFB, Ohio.[6] Conversely, the Navy could draw civilian staff from the Naval Air Systems Command and other organizations located in the Washington, D. C. area, so their part of the JCMPO comprised nearly 150 civilians and between 30 and 40 uniformed personnel.

Air Force-JCMPO Disagreements

The outcome of the March 7, 1980, USDR&E decision was that management control of the ALCM would be transferred to the Air Force, while management responsibility for the GLCM and common subsystems would remain with the JCMPO at least though the GLCM DSARC III. This, coupled with the earlier differences of opinion, led to further disagreement between the Air Force and JCMPO. A Systems Acquisition Management Inspection (SAMI) was conducted by the HQ USAF Inspector General's office between March 1980 and March 1981 to evaluate the ongoing GLCM program. Two findings of that study were that an extremely high risk situation existed because of a concurrent schedule (missile production before completion of support equipment development), and that the JCMPO management structure was not effective with regard to the GLCM, MRASM, and common subsystems. Two recommendations from the study were that a DSARC type of review of the GLCM program should be held before the production phase, and that consideration should be given to a management transfer of the GLCM, MRASM, and common subsystems to the Air Force.

The results of that study, in part, led to the Air Force position that those programs and systems should be transferred to its management control. A plan was formulated that included four alternatives ranging from dissolving the JCMPO to retaining it (albeit in a weaker position).

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[6] The Air Force also maintained an engineering staff, largely civilian, at Wright Patterson AFB.

One alternative was to transfer the MRASM to the Air Force, and leave all other programs and systems with the JCMPO. That alternative was supported by two arguments: a large Air Force versus Navy buy (approximately 2500 versus 1000), and the Navy's continuing attempt to withdraw from the MRASM program altogether in favor of a modified Harpoon. On February 2, 1981, Dr. Walter B. LaBerge, Acting Under Secretary of Defense For Research and Engineering, directed that developmental activities for the Navy MRASM be terminated because the Navy had reduced priority and funding for that project, and that the Air Force should assume the management of the AGM-109H MRASM effort and related submunition and guidance development programs. That directive provided justification for the Air Force to attempt to gain control of the MRASM program, although it was not specified whether the MRASM should be removed from the JCMPO or simply managed by Air Force personnel at the JCMPO.

The second Air Force alternative involved removing the MRASM and the GLCM Launch Control Subsystem, Command, Control and Communication system, and the Transporter, Erector, Launcher while leaving the GLCM and SLCM airframes and common subsystems at the JCMPO. The third alternative was to remove the MRASM, the GLCM systems previously mentioned in the second alternative, the F107 engine, and the navigation/guidance system while leaving the SLCM, the GLCM and SLCM airframe, and the mission planning system at the JCMPO. The fourth alternative would basically disband the JCMPO, leaving the Navy to manage the SLCM program. The Air Force advocated the third alternative, and argued for a transition of the GLCM and MRASM to be complete before the end of FY81. Pending the outcome of the Air Force attempt to convince OSD that its plan should be approved, it held off assigning new and additional personnel to the JCMPO.

Although no supporting documentation was found, it seems likely that OSD intervened in this debate and forced a resolution of the issues because cooperation between the Air Force and the JCMPO on the GLCM and MRASM programs improved shortly thereafter. In the case of the GLCM, a Terms Of Reference was signed between Rear Admiral Locke, Admiral Whittle, CNM, and General Marsh, AFSC Commander, on May 8, 1981, to "insure a successful management effort for development and initial

deployment of the GLCM program." In these terms it was agreed, among other things, that the program direction, funding, and functional reporting for the GLCM program would be through AFSC, while funding for common items would be coordinated with the CNM; the acquisition policies and procedures of the Air Force would be used to the maximum extent possible; the GLCM office would be located within the JCMPO, with personnel, contracts, budgets, and management systems segregated to the maximum extent possible; and that the Air Force would provide an additional 27 personnel to the JCMPO for the GLCM program. With the signing of the Terms of Reference and the implementation of its items, both the Air Force and the JCMPO recognized the other's organizational concerns and set forth solutions that in effect strengthened the management and the development process of the GLCM program. Within 90 days of the signing of the Terms of Reference, the AFSC had staffed nearly all of its positions. Meanwhile, the Navy eliminated 15 civilian positions in the MRASM staff as part of an effort to reduce its involvement in that program.

Appendix B
DMA/JCMPO INTERACTION

The land-attack cruise missile is the first deployed weapon system that utilizes maps stored in an onboard computer to update the vehicle's inertial navigation system (INS)[1] along the flight path.[2] Because additional systems of this type will probably be deployed in the future, the successful cooperation between the Defense Mapping Agency (DMA), Service program offices, operational commands, and appropriate contractors was necessary to ensure the operational performance of the host vehicle, as well as its timely deployment. It is therefore useful to examine the interaction between the DMA and JCMPO to provide future program managers with an understanding of the complexity and necessary scheduling for the generation of support data for terrain matching guidance updating systems and, more generally, of inter agency coordination. A discussion of the costs of DMA services provided to the cruise missile program is contained in Appendix I.

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[1] Throughout the remainder of this Note, INE will be used to designate the inertial guidance platform, digital computer, and power supply for the land-attack GD/C and Boeing cruise missiles. An INE, together with a radar altimeter and chassis, constitutes a Reference Memory Unit and Computer (RMUC). When integrated into a package, the RMUC is known as the Cruise Missile Guidance Set (CMGS), which is provided by MDAC for the GD/C Tomahawk land-attack cruise missile. Boeing takes the INE, provided by MDAC, and adds a separate autopilot and associated computer and radar altimeter. The result is a distributed navigation/guidance subsystem that is incorporated in their ALCM (AGM-86). The generic term, Inertial Navigation System (INS) will be used for the inertial portion of the Boeing and GD/C land-attack cruise missile guidance subsystems.

[2] The Automatic Terrain Recognition and Navigation (ATRAN, a trademark of Goodyear Aerospace Corporation) system was used on the TM-76A MACE missile deployed in Europe during the late 1950s and early 1960s. The ATRAN system provided continuous missile navigation without the use of an INS, which at the time was not suitable in such a system because of cost and performance considerations. However, potential cost, reliability, and survivability problems preclude continuous mode operation for moderate to long range distances in current cruise missiles.

TERCOM AND TERRAIN FOLLOWING OPERATION

The operation of a map-matching guidance system and the preparation of terrain data needed by that system are parts of a rather specialized process. To help the reader understand the subsequent discussion of institutional interactions, we first provide a brief introduction to Terrain Contour Matching (TERCOM),[3] how TERCOM maps are screened and evaluated,[4] and terrain following.

Definitions

A TERCOM *map* is simply a rectangular array of digital terrain elevations, above Mean Sea Level (MSL), located along the predicted flight path of the cruise missile. It is the portion of terrain over which a correlation will be done with sensed data to determine INS error. Each elevation value represents an average for a particular square cell. These cells may vary in size. For example, a 300 foot cell would contain the average terrain elevation value above MSL within a square area whose edge is 300 feet long (and whose area is 90,000 square feet). The cell sizes used may vary during the course of the mission depending upon the desired accuracy and reliability, and on missile computer storage capacity.

A TERCOM *update area* is a TERCOM map, or map set, prepared by DMA that has successfully passed through an evaluation procedure to ensure its quality and is suitable for use in the cruise missile guidance system. The test strip or column of data is the one-dimensional (down-track) profile generated by the forward motion of the cruise missile, coupled with the operation of the downward oriented radar altimeter. The term "terrain matching" refers to the "correlation-like" process whereby the reference map (stored in the missile's onboard computer) is

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[3] For a primer on TERCOM, see Joe P. Golden, "Terrain Contour Matching (TERCOM): A Cruise Missile Guidance Aid," in *Proceedings of the 24th International SPIE Symposium*, July 28-August 1, 1980, pp. 10-18.

[4] For a primer on map-matching guidance updating systems and the reference scene selection problem, see Edmund H. Conrow and Joseph A. Ratkovic, "Almost Everything One Needs To Know About Image Matching Systems," in *Proceedings of the 24th International SPIE Symposium*, July 28-August 1, 1980, pp. 426-453.

compared with the "live" sensor data to determine the location of best match. This information is then used to update the state of the Kalman filter within the guidance system to help correct errors resulting from imperfect gyroscopes and accelerometers. Hence, TERCOM is a terrain (or map) matching guidance updating system.

Each TERCOM reference map comprises a given number of cells in the down-track and across-track directions, determined in part by the expected INS errors (hence missile position error) at a given point within the flight and the characteristics of the terrain matching correlation algorithm used. Each TERCOM reference map also has a given azimuth orientation relative to a true north heading to facilitate the mission planning process.

TERCOM

In the cruise missile, a guidance updating system is needed to aid in the removal of time-varying error sources within the INS (primarily because of gyroscope drift and accelerometer bias). In the TERCOM system, a terrain profile computed inflight from barometric/inertial and radar altimeter data is compared with one determined beforehand and stored in the onboard computer.[5] (This predetermined data is the DMA TERCOM map). A correlation-like algorithm (Mean Absolute Difference) is then used to determine in near real time the position of "best match" between the down-track (one-dimensional) altimeter test data and the two-dimensional computer stored reference map.

The difference between the location of "best match" and the vehicle's estimated location (derived from the INS) provides an estimate of the down and across-track position errors that are present at the time of the update. The information is then utilized in the missile's onboard Kalman filter not only to introduce a flight path correction to "steer out" the errors, but to reduce their time-varying growth during the course of the flight. The net result is that the INS error accumulation may be substantially reduced during the course of a flight through several sets of TERCOM updates.

[5] The Digital Scene Matching Area Correlator (DSMAC) system is used in conjunction with TERCOM to provide higher accuracy in the terminal guidance phase of conventionally armed land-attack SLCMs and MRASMs. This increased accuracy is not needed for nuclear-armed land-attack variants because the warhead has a much larger kill radius.

During the course of the cruise missile flight, different sizes of TERCOM maps are utilized to account for the variations in INS accuracy, algorithm performance, and onboard computer storage capabilities. Thus, for the initial or landfall update, fairly coarse cell sizes can be utilized because minimum flight error is not as critical as ensuring a reliable update to help remove potentially large position errors. These could be up to several miles in cases where initial position and velocity values from the launcher or carrier were poor or there is a long standoff launch range over water (where TERCOM is not applicable). The enroute, midcourse, and terminal maps utilize data with progressively smaller cell sizes, because the missile guidance system error should have been reduced by previous updates and to provide increasingly more accurate estimates of the INS error characteristics.

To permit estimation of the down and across-track INS velocity errors and to increase overall reliability, most TERCOM updates utilize three individual correlations performed in succession. Because a non-doppler system is used, velocity errors cannot be estimated from a single correlation. Given the importance of this component in the resulting cruise missile position error as it propagates with time (even if zero initial position error existed), a velocity error estimation technique--two or more successive correlations--is needed to compensate. When these multiple correlations are coupled with a voting logic (e.g., two out of three correlations must match to have a valid TERCOM *update*), the probability of obtaining a false update can often be substantially reduced.

Reference Map Screening and Evaluation

The DMA prepares each candidate TERCOM reference map from a digital matrix of terrain elevation data. The matrix location is determined by terrain roughness and uniqueness considerations coupled with mission planning considerations. The objective is for the map to meet mission planning constraints and to have a high probability of correct correlation (PCC) value.

Given a terrain elevation matrix of suitable roughness and uniqueness, a number of computer programs and subroutines are used to ensure that the terrain selected for a reference map will support proper TERCOM operation. First, an interactive computer program called STAT prepares candidate reference map files, calculates terrain roughness statistics, and presents abbreviated AUTOMAD results. STAT assists in quickly identifying and evaluating the most likely sites for the desired maps. The AUTOMAD computer program is the central routine for the map selection and validation process. It performs all TERCOM correlation operations done in flight. There is no true measured altimeter profile available; therefore, AUTOMAD uses the reference terrain profile itself, a more complex and costly Monte Carlo simulation is avoided, and a considerable amount of time and money are saved. The results achieved during flight testing have demonstrated a high degree of confidence in the PCC values computed by the AUTOMAD program.

The complexity of this simulation makes it necessary to validate the individual submodels present by extensive flight testing. This is typically performed by means of tests in aircraft equipped with a Cruise Missile Guidance Set (CMGS) to reduce overall program costs. Flight testing is also performed to evaluate the suitability of candidate changes to the TERCOM system (i.e., altimeters, and terrain elevation data obtained from different sources), as well as to validate the performance of the system over operationally representative terrain.

Terrain Following

To enhance survivability, land-attack cruise missiles can use a low altitude terrain following mode to minimize the probability of detection when over hostile territory. A safe terrain following clearance Above Ground Level (AGL) is determined for each leg of the flight during mission planning by running missile simulations over Digital Terrain Elevation Data (DTED) and Vertical Obstruction Data (VOD) along the route. These "clearance plane settings" above the terrain are then preset into the missile computer along with other mission commands prior to flight. In flight, the missile enters and departs the terrain following legs using altitude information from the radar and

barometric/inertial altimeter subsystems. Once in the terrain-following mode, the missile attempts to maintain the desired clearance plane altitude using only the radar altimeter data[6] and appropriate throttle and pitch controls.

The data used in the terrain following process and in the clobber analysis[7] module simulations during mission planning are an overlay of the DTED and VOD files. The DTED is primarily oriented toward natural terrain elevation characteristics, and that in the VOD file includes man-made features whose AGL height is greater than some prescribed value.

DMA/JCMPO ORGANIZATIONAL INTERACTIONS

The DMA provides three different types of digital data supporting the cruise missile program. The first is TERCOM, which is processed into digital maps of predetermined areas, stored in the missile's onboard computer and used in the guidance updating process. The other two types are the DTED and VOD. The primary use of these data is in the automated mission planning system where they are used in routing (terrain, obstacle, and defense avoidance) and clearance plane setting (terrain and obstacle avoidance decisions).

The initial DMA/JCMPO interaction resulted from the DMA's mission, as established in DoD Directives in 1972, as the overall manager and producer for mapping, charting, and geodetic products. Before the formation of the JCMPO, the individual Air Force and Navy program offices came to the DMA for data bases and information about them. Potential missile users also came to the DMA for this information. As the size and complexity of the cruise missile program grew, several DMA decisions were made. These included the establishment of a full time DMA cruise missile program manager to monitor and direct program support; the formation of a cruise missile steering group composed of DMA senior staff to examine management, program progress, and problems; and the allocation of special security clearances to contractor

[6] A "down-looking" system rather than a "forward-looking" system is used to minimize the probability of enemy detection.

[7] When vertical obstructions are present along the flight profile, the command AGL clearance is increased to prevent "clobber" (flying into an obstruction).

engineering personnel to assure their total understanding of the DMA data.

The existing DMA management organization and normal internal coordination between Requirements and Production Directorates were used to support the cruise missile program. The DMA Requirements Directive defined the quality and quantity requirements for TERCOM reference maps based upon JCMPO, and later, operational command inputs, and assigned them for production. Ad hoc working groups were formed as needed for particular problems as they occurred with membership appropriate for the issues. To date, user interaction has been effective throughout the ALCM program, with daily to weekly contact at the action officer level and monthly briefings conducted for the senior staff between the DMA and the Joint Strategic Target Planning Staff and the Air Force Strategic Air Command (JSTPS/SAC). Contact with GLCM and SLCM theater users and Service monitors was initially minimal but has increased to parallel the JSTPS/SAC interaction as the IOCs for the individual missiles approach.

These interactions are described below in further detail through description of the three basic DMA activities: data base development, data base production, and data testing.

Data Base Development

Before the imposition of any requirements from the cruise missile project, the DMA possessed the technical capability (equipment and techniques) to produce digital data for terrain following and TERCOM. The DTED data, used in part for cruise missile terrain following, has been in production since the early 1970s, primarily in support of the Digital Landmass System (DLMS), which provides terrain representations for aircraft simulators. Consequently, little was initially needed in terms of R&D or rate production techniques to support the cruise missile project. In the case of TERCOM, DMA had been producing high quality digital elevation data for developmental flight testing in support of this project since the early 1970s. This basic product was used for TERCOM Aided Inertial Navigation test flights (sponsored by the Navy Cruise Missile Project Office) that were started in March 1973, for contractor's TERCOM test flights, and for the competitive flyoff for the cruise missile guidance system ending in October 1975.*

* Additional discussion of the flight tests is contained in Appendix C.

Initially, in the TERCOM guidance updating system the DMA principally generated terrain elevation data for the map-making process. Test areas were digitized from regions identified by the contractors (Boeing and McDonnell Douglas Astronautics (MDAC)) and their service sponsors (the Air Force and Navy, respectively). Specific data cell sizes, azimuth orientation, and dimensions for the area to be digitized were identified with each request to the DMA to meet specific test requirements. From the digital elevation data matrix provided by the DMA, the contractors selected maps to be used. On June 30, 1977, the Navy cruise missile project office transmitted a letter to the DMA establishing requirements for the data base to support the cruise missile TERCOM and terrain following programs. The DMA began to develop the expertise to produce TERCOM maps during 1977 from the use of the selection process that had been supplied by the JCMPO by the Applied Physics Laboratory at Johns Hopkins University and, later, MDAC. Initially, the DMA used that process to try to duplicate the MDAC reference maps selection process from a previously produced (DMA) digital elevation data matrix. As the DMA became more proficient at the reference map selection process, it began to produce the TERCOM reference maps used for flight tests with JCMPO approved software selection criteria.

The technical approach used by Boeing and MDAC for TERCOM reference map size and selection were considerably different, however, and if allowed to continue, could have caused the DMA to produce duplicate TERCOM reference scenes in any joint use (ALCM-SLCM) operational area. The diversity of technical requirements also caused confusion in the ALCM user community, which resulted in the JSTPS/SAC also determining their own technical needs for TERCOM. (The JSTPS/SAC requirements were motivated by the ALCM competitive flyoff announced on September 30, 1977.) Because of the potential effects on cost and output that could create, owing to the different contractor approaches for implementing TERCOM, the DMA requested that the newly formed JCMPO establish a single set of technical TERCOM specifications.

On November 2, 1978, the JCMPO gave the cruise missiles data base specifications and requirements to the DMA. The intent was to revise and expand the June 30, 1977, guidelines previously provided to the DMA

for the generation of data bases required by nuclear armed land-attack cruise missiles that utilize terrain following and TERCOM. In addition to specifying the need for the terrain following and TERCOM data bases, the JCMPO provided information and guidance on the structure of the data bases and the intended use of each in planning cruise missile missions. The guidance was specific to the degree necessary to avoid duplicative work by the DMA, yet left enough flexibility to allow mission planners to meet individual requirements of the ALCM, GLCM, and SLCM programs. The technical specifications and requirements provided to the DMA were based upon those provided to the JCMPO by the Applied Physics Laboratory, which had served as technical advisors to the JCMPO on terrain following and TERCOM. The JCMPO at that time also specified that the most accurate source material be used for the generation of TERCOM maps until more testing could be performed. Although that would potentially result in a higher cost per reference map than if a lesser quality source material was used, the DoD followed the conservative route initially because of the strategic importance of the ALCM and the lack of conclusive testing relating to performance of TERCOM maps generated from the lesser quality source material.

At that time, two things the DMA did not have for generating TERCOM reference scenes were the selection and validation process and a sufficient production capacity to generate the required quantity of data. Although the former constraint was rectified by the specifications and requirements given in the JCMPO letter of November 2, 1978, the latter required coordination among the DMA, the OSD, the JCMPO, and the user community to correct. That was accomplished through procurement of additional photogrammetric equipment (including a dedicated TERCOM processor) and additional personnel to support the DMA TERCOM activity. The use of existing DTED data greatly reduced the scheduling and cost burden for the production of the cruise missile terrain following data base.

Data Base Production

The technical requirements for the terrain following data base were established by the JCMPO on June 30, 1977. Because the data samples produced from DTED and tested up to that time supported the existing cruise missile penetration altitudes, DTED was selected for this role. As the operational users had already stated DTED requirements for their programs (through the DLMS), no new development requirements were generated for terrain following input data at that time. These considerations, coupled with the fact that DTED was scheduled for completion (first time coverage) in the mid-1980s, influenced its selection.

To acquire the first time coverage, the DMA uses both cartographic and photographic source materials in the priority areas. Because of the lack of photographic coverage, equipment limitations, and manpower availability to produce photographically derived DTED in the desired time frame, cartographic sources are used to fill areas void of photo coverage and to expedite the availability of data.[9]

As emphasis shifted to lower cruise missile penetration altitudes, vertical obstructions took on increased importance. The role VOD will play in the mission planning functions is currently being defined. Until recently the mission planning system software was not available to utilize these data. Some technical problems still need to be answered to ensure proper use of vertical obstruction information. VOD was already being collected as part of the Digital Feature Analysis Data, but not in the format or detail required to support cruise missiles. The DMA began technical studies in 1979 to determine the feasibility of collecting VOD, and began producing it in approximately the current format in FY81.

The factors influencing TERCOM production, however, were quite different. Because of the long lead time needed for funding, procurement, and production, the users were not able to provide

[9] As photographic materials and equipment become available, the DMA will replace the cartographic data where the accuracy requirements are not satisifed. Current plans are to have first time coverage completed by FY86 and the cartographic data replaced by photographic data by FY89.

definitive quantitative requirements for the initial program decisions. Therefore, initial production program decisions were based on *hypothetical* requirements for 5000-6000 update areas and included specifications for the various reference scene types used (landfall, enroute, midcourse, and terminal) during the flight of a nuclear armed land-attack cruise missile. With the limited production experience of a few test matrices, the DMA designed a production plan for these reference maps over a period coinciding with the planned missile procurement schedule. The JSTPS/SAC then set their total operational requirements for the ALCM, and later, a "minimum essential" requirement that was roughly 80 percent of the then-estimated DMA capability. The GLCM and SLCM were scheduled for a later IOC and followed the JSTPS/SAC lead.

The initial data requirement was small and supportable out of available R&D program funding, but support for the various Initial Operational Capability (IOC) dates did require program decisions to be made in early 1979. While overall DMA resource allocation is guided by OSD and JCS priorities, to follow this explicitly (that is, to support "priority one" programs at the exclusion of all others) would have put all resources in support of the ALCM. The result would have been a fielded GLCM and SLCM with little operational capability. To avoid this potential problem, DMA management coordinated a 75 percent ALCM/25 percent theater (GLCM and SLCM) division of resources. That decision was initially accepted by the operational users, although it has since been modified to account for individual missile IOCs, duplicate operating areas, and specific command areas of responsibility.

Data Testing

Initial data base quality requirements for TERCOM were not stated in the conventional manner (i.e., a specific accuracy relative to a specific datum, at a specific confidence level). Instead, DTED was accepted "as is" and TERCOM was specified to be generated from a particular source material. Similarly, cell sizes constituting the data base were accepted "as is" for DTED, while TERCOM testing was done at various cell sizes, although there has been no change in operational cell sizes since those initially established by the JCMPO on November 2,

1978. There has also been no change in TERCOM map dimensions since November, 1978. Evaluation of map quality for TERCOM is related to the PCC (or update), and is estimated a priori by means of validated DMA computer simulations of the update process. On November 2, 1978, the JCMPO also established the MDAC criteria, termed "AUTOMAD," as the map screening metric. Eventually, the JCMPO developed a more sophisticated (albeit more costly) PCC simulation in 1981 based on software developed by the Applied Physics Laboratory and MDAC and on MDAC flight test results from designated TERCOM areas. Revisions to the process are being made that tag each reference map's quality so that the user can determine its acceptability based upon the existing mission requirements.[10] Finally, the initial requirements for reference map locations were limited to identification of potential cruise missile operating areas. Here, the DMA would identify areas where TERCOM was feasible and from that the users would identify specific map locations. At the present time, the map location designation process is still in progress.

Alternate data sources and processes were examined before and during the TERCOM production phase. Because the initial requirement was for DMA's best and most expensive product, those examinations were slanted toward reducing cost and increasing output while maintaining an acceptable level of quality. The JCMPO has approved an alternate TERCOM source that can considerably reduce the cost of producing some TERCOM reference scenes. Attempts are underway to better quantify a reference scene's quality and, to a certain extent, permit the selection of TERCOM reference scenes based upon user mission requirements.

Results from TERCOM flight testing[11] by contractors have resulted in the downward adjustment (more liberal) of previously established reference scene validation criteria. These changes have generally increased map production rates, although a new validation process developed by the JCMPO may have either a positive or negative effect on the process.

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[10] This will probably lower the minimum acceptable map quality required, hence reduce overall program costs.

[11] Additional discussion of the flight tests is contained in Appendix C.

Initially, the JCMPO accepted DTED as adequate for terrain following use, based on early testing of photogrammetric data. As previously mentioned, the DMA produced both the cartographic and photographic DTED to satisfy operational requirement dates and to provide first time coverage. Detailed testing of DTED is now under way to determine its suitability for terrain following and to determine if modifications to the DTED data base are necessary.

Appendix C
CRUISE MISSILE TEST PROGRAM

This appendix briefly sketches the historical development of Test and Evaluation (T&E) management within the JCMPO. The T&E program for each cruise missile variant is discussed, except for the Navy MRASM (AGM-109L), for which a Test and Evaluation Master Plan (TEMP) has not yet been prepared.

The DoD T&E process normally includes three phases performed during the system acquisition process: Development Test and Evaluation (DT&E), Operational Test and Evaluation (OT&E), and Product Acceptance Test and Evaluation (PAT&E). As defined in DoD Directive 5000.3, "DT&E is that T&E conducted to assist the engineering design and development process and verify attainment of technical performance specifications and objectives." OT&E is defined as

> that T&E conducted to estimate a system's operational effectiveness and operational suitability, identify needed modifications, and provide information on tactics, doctrine, organization, and personnel requirements. Acquisition programs shall be structured so that OT&E begins as early as possible in the development cycle.

Follow-on testing (FOT&E) is conducted after the Milestone III decision to "ensure that the initial production items meet operational effectiveness and suitability thresholds and to evaluate system, manpower, and logistic changes to meet mature system readiness and performance goals." Finally, PAT&E is defined as "T&E of production items to demonstrate that procured items fulfill the requirements and specifications of the procuring contract or agreements." Also defined in DoD 5000.3 is the need and requirements for the preparation of a TEMP. The Directive states that "this broad plan shall relate test objectives to required system characteristics and critical issues, and integrate objectives, responsibilites, resources, and schedules for all T&E to be accomplished."

JCMPO T&E PROGRAM DEVELOPMENT

One concern expressed by the OSD T&E community before the cruise missile DSARC II was that the individual Air Force and Navy T&E programs had no effective exchange of test data or common planning. As a result, a form of common T&E management structure that would require fewer test vehicles was recommended to reduce financial expenditures and schedule time. In his January 14, 1977, DSARC II decision memorandum, Deputy Secretary of Defense William Clements recognized joint Service T&E as one area that would potentially produce benefits, and specified that it would be used fully in the development of each cruise missile version. Mr. Clements also directed that a joint Service TEMP be submitted for DDT&E review 90 days following the issuance of his decision memorandum, and that it contain a "realistic missile employment test and penetrativity evaluation." Although a joint TEMP was prepared which referenced individual missile version TEMPs, it was never formally approved (but only, apparently, because there was no practical procedure for joint service approval of a TEMP). The initial ALCM TEMP was published in November 1976, with the most recent update approved in March 1980. The initial GLCM TEMP was approved in February 1982. The SLCM TEMP was first approved in June 1977 and has been updated yearly since then. It is being split into two TEMPs for ship and submarine launch platforms. A TEMP for the Air Force MRASM (AGM-190H) is currently in review, and that for the Navy version (AGM-109L) will be incorporated in a subsequent revision or issued as a separate TEMP.

A summary of the overall cruise missile test program for each version from DSARC II is given in Fig. C.1 (provided by the JCMPO).

SLCM TEST PROGRAM

The SLCM began accumulating test results several years before the formation of the JCMPO. From June 1972 to June 1974, engineering models of conceptual configurations were subjected to wind tunnel, underwater launch, and radar cross section tests to demonstrate that achievent of program objectives was technically possible. The data from those test and associated analyses provided a basis for system design and resulted in congressional approval to proceed with the Competitive Demonstration Phase.

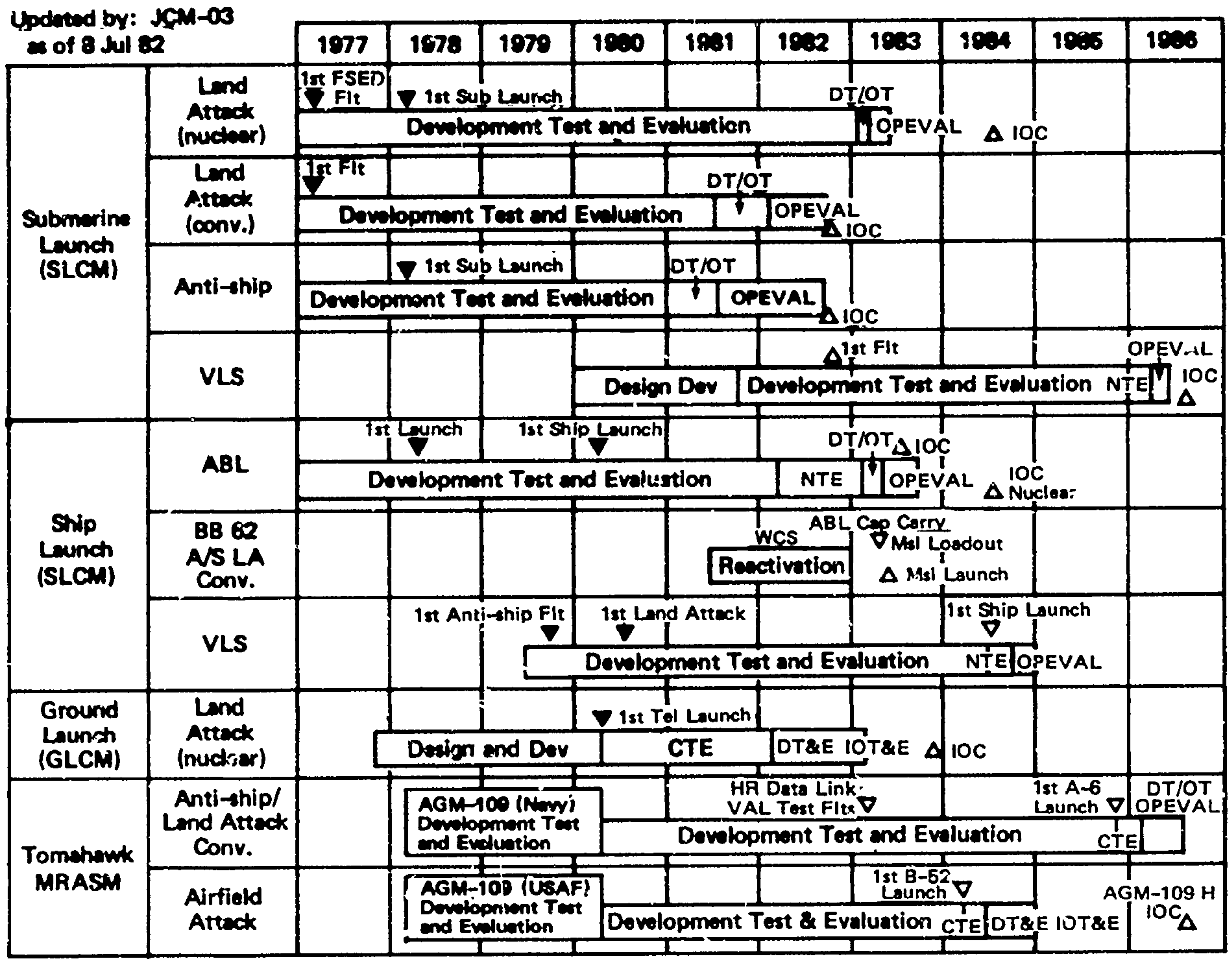

Fig. C.1 -- Tomahawk test program schedule

From July 1974 through March 1976 the Competitive Demonstration Stage of the Validation Phase utilized full-scale prototype models and components to support Tomahawk development. The tests resulted in selection of the systems integration, airframe, guidance, and sustainer engine contractors.

From April 1976 through December 1976 the Systems Integration Stage of the Validation Phase utilized six recoverable prototype missiles for Tomahawk flight tests. Fifteen flight tests over water and land demonstrated Tomahawk's ability to operate within the required performance envelope. Operationally realistic demonstrations were also conducted from February 1974 through December 1976. Subscale models, full-scale inert test vehicle, captive test vehicle, and prototype land-attack and anti-ship cruise missiles were utilized.

From January 1977 through December 1979, 31 flight tests of 12 recoverable prototype vehicles were conducted. In addition to those flight tests, captive and launch tests aboard A-3 aircraft were conducted in which anti-ship seeker performance in various environments was evaluated.

In response to congressional criticism that too many SLCM tests were being conducted vs. GLCM and ALCM tests, the JCMPO and the Navy's Commander of Operational Test and Evaluation Forces (COMOPTEVFOR) jointly conducted an in-depth review of the SLCM T&E program in the summer of 1979. In addition to ensuring the best use of resources, the evaluation was conducted to determine the best way, given production funding direction at that time, to achieve the congressionally directed IOC for the conventionally armed land-attack SLCM.

Based on the review, a proposed restructured SLCM T&E program was defined and recommended to the Chief of Naval Operations (CNO). It differed from the previously approved SLCM T&E program chiefly in that it employed combined Development Testing (DT) and Operational Testing (OT) during the period normally reserved for Navy Technical Evaluation. The Tomahawk program was capable of this juxtaposition because common objectives between the JCMPO and COMOPTEVFOR allowed sharing of the flights. In addition, the restructured SLCM T&E program featured concurrent anti-ship and land-attack Tomahawk testing on both submarines and surface ships. That would greatly reduce the effect of Tomahawk

testing on fleet resources as well as reduce the number of flights in the anti-ship and land-attack submarine (launch) programs. The net result was the release of nuclear land-attack and anti-ship SLCM assets. This providing additional missiles for conventionally armed land-attack SLCM development testing without increasing the total number of SLCM program test flights, thereby satisfying congressional direction to achieve an early IOC for that system. Although the combination of service developmental and operational testing has recently become a common practice in the Air Force, and is being used for the GLCM program, the SLCM OT&E plan was the first time it had been done on a major Navy missile program.

The key to the restructured SLCM T&E program was the combined DT/OT. The JCMPO and COMOPTEVFOR, which began working together in 1977, developed a set of detailed ground rules to manage the combined DT/OT for SLCM. They include, among other things, the requirement that COMOPTEVFOR be included in the SLCM Weapon System Configuration Control process. As a result of developing those ground rules, the CNO directed the JCMPO on October 9, 1979 to restructure the SLCM T&E program to incorporate combined DT/OT subject to specified conditions, and revise the SLCM TEMP to reflect the restructured program.

A critical issue in the initial operational test and evaluation (IOT&E) was the limited number of DT/OT and operational evaluation flights available to evaluate a complex, multi-mission weapon system. A statistically significant evaluation of Tomahawk weapon system effectiveness would be possible only if operational data could be supplemented by valid computer-generated flight simulation data. As stated in the SLCM TEMP, this would be especially true in the areas of survivability, terminal phase effectiveness, and countermeasures performance.

Test launches from surface ships were conducted from January through April 1980. Two launches were conducted to demonstrate Armor Box Launcher (ABL) and surface ship launch compability, and over-the-horizon (OTH) targeting.

The first phase of operational testing was conducted from January 1977 through February 1978. Recoverable prototype missiles were launched and flown to assess actual achievement of program objectives.

Flights were made in as realistic an operational environment as possible consistent with program phase. Successful accomplishment of these tests supported the COMOPTEVFOR recommendation to commence pre-production prototype (PPP) fabrication.

Further operational testing was conducted from March 1978 through December 1979. Recoverable prototype and PPP missiles were flown by the JCMPO and observed by COMOPTEVFOR to assess the achievement of program objectives. During this test phase 23 launches were performed. In a continuation of those tests, recoverable PPP missiles will be launched and flown by the developing agency during Navy contractor test and evaluation to verify readiness to proceed to DT/OT and to assess achievement of program objectives.

During future FOT&E tests, improvements to the Tomahawk weapon system will be verified and tactic development continued. In addition, operational effectiveness and suitability of major modifications/improvements to the Tomahawk weapon system will be assessed that are currently planned or that may evolve. At the present time, four Pre-Plannned Product Improvement (PPPI) item tests are planned that are generic to the SLCM, seven PPPI item tests are planned for the anti-ship variant, and 11 PPPI item tests are planned for the land-attack variant. Examples of these items include an improved booster (generic), ring laser gyro mid-course guidance (anti-ship), and new conventional warheads (land-attack).

Critical T&E issues for the Tomahawk SLCM systems, based on risk areas identified in the SLCM Executive Program Summary, are given in Table C.1 These issues are divided into categories applicable to both the land-attack and anti-ship variants, and each variant separately.

A post-IOC test program is being configured that will provide an effective measure of the operational readiness level of the cruise missile force. Program considerations in this T&E include the number of variants, the tactical/strategic nature of the weapon, the quantity/variety of platforms, the operational complexity, and the recoverable nature of the missile itself when a Recovery Exercise Module (REM) is installed. The latter point is important because it permits SLCMs to be tested, recovered at an estimated 75 percent rate, rearmed, and returned to the fleet. This should reduce the number of

Table C.1

SLCM CRITICAL T&E ISSUES

General[a]	Land-Attack Tomahawk	Anti-Ship Tomahawk
Reliability	Terrain Following	Warhead Effectivenss
System Compatability	Range	Target Intercept
Shock Resistance	Warhead Qualification	Area Search Execution
Qualification	Mission Planning	PI/DE Capability
Logistics Support	Navigation Accuracy	Mission Planning
Maintainability		Maneuverability
Launch Platform Motion		ECM Vulnerability
Replenishment/ Reload at Sea		
Survivability		
Interoperability		
Weapons Compatability		

[a] Applies to both land-attack and anti-ship Tomahawk systems.

missiles expended during the test program, hence the total program cost and burden on the fleet armament capability.

Reliability and Readiness Testing

Operational readiness is the probability that a cruise missile will be successfully launched and will hit the target. Operational readiness is not interchangeable with production reliability. There are two contributing factors to operational readiness--missile system readiness, which includes storage and free flight reliability and launch and hit

probability considerations; and platform readiness, which is primarily a function of launch control system availability. The test objectives of the operational readiness assessment include performance characteristics, planning factors not degraded during system life, determination of the adequacy of tactical producures, diagnostics for system improvement, and crew training.

The approach to be used by the JCMPO will combine both operational readiness and platform certification tests to further reduce costs. Coupled with the recoverable nature of the SLCM, this is expected to yield the necessary test data and satisfy fleet requirements at a substantially reduced cost and burden on the inventory.

One major objective of the test program was to demonstrate an adequate level of missile reliability. Because reliability is influenced by handling and maintenance of the missile by the operational user, as well as by the development and manufacturing procedures, a brief description of operational support procedures and reliability warranties is given here.

As stated in the SLCM TEMP, the "anti-ship and land-attack Tomahawk cruise missiles are being procured under an All Up Round (AUR) warranty concept which includes contractor maintenance for the life cycle of the weapon system." Successful accomplishment of the warranty will be determined in terms of three guarantees: missile Operational Test Launch (OTL) Reliability; missile Recertification/Readiness Reliability; and missile Turnaround Guarantee.

For OTL Reliability, the SLCM TEMP directs that the contractor

> will guarantee that a specified percentage of Tomahawk flight trial missiles will successfully fly the specified missile profile from the launch platform to the target. Flight trial missiles will be randomly selected from fleet assets by the Navy and returned to the contractor for the REM or range safety system installation. Dual government and contractor inspection will occur during this evaluation to ensure that REM installation and minimum checkout is performed to ensure similarity to the present fleet populaion. The missile will then be returned to the designated launch platform for firing.

In the case of missile Recertification/Readiness Reliability, the contractor

> will guarantee that a specified percentage of Tomahawk recertification tests and sample readiness tests on missiless will successfully meet test requirements. The warranty recertificaion provides periodic planned test and maintenance actions which are specifically designed to renew the contractor's confidence in the warrantability of the missile. The readiness test will be performed on a sample basis as selected by the government and extensively exercise the missile in a simulated mission environment test.

For the Turnaround Guarantee, the contractor will guarantee that all missiles returned to them for recertification will be returned to the fleet in a specified period of time.

Product Acceptance Testing

Data for the Tomahawk weapon system PAT&E program is derived from five different sources, including: Final Factory Acceptance Tests (FFAT), Qualification/Reliability Sampling Tests (Q/RST), Operational Test Launches (OTL), Missile Readiness Tests (MRT), and Missile Readiness Recertification Tests (MRRT). The objective of the FFAT is to assure that the

> weapon system production components or prime items demonstrate meeting specification requirements prior to offical Government acceptance. It will be performed by the applicable contractor at specified component and/or system levels on a 100 percent basis. Satisfactory completion of these tests will provide initial certification of (missile) operational capability at the start of the specified warranty period.

The objective of the Q/RST is to assure that the

> production components or prime items continue to meet specification reliability and performance requirements. These tests will be performed at the systems/component level, on a sampling basis, and will include storage and worst-case environment mission simulation tests.

The OTL, MRT, and MRRT tests are a portion of the Warranty Verification Tests for the SLCM. For OTL, periodic fleet-conducted launches are to be performed on a sample basis to measure the missile Warranty Flight Trial Guarantee requirements. For the MRT, missile environmental/mission simulation tests are to be conducted on fleet SLCMs on a sample basis to evaluate the Warranty Missile Readiness/Reliability Guarantee performance. Finally, for MRRT, every missile returned to the contractor for warranty recertification will be tested to measure the Warranty Missile Readiness/Reliability Guarantee performance.

A summary of the GD/C cruise missile flight test results to date is given in Table C.2. Flight test results are presented for the GD/C candidate ALCM (AGM-109), and GLCM and SLCM vehicles (BGM-109). TERCOM and DSMAC updates performed correspond to land-attack variants (only), with DSMAC information being applicable to only the conventionally armed land-attack variant.

Summaries of some of the key test flights are given in Table C.3.

Table C.2

GD/C CRUISE MISSILE FLIGHT TEST SUMMARY

	AGM-109	BGM-109
Flights [a]	10	79
Flight time (hrs:min)	22:22	65:22
Flight distance (n mi)	9,595	28,602
Navigation distance (n mi) (air carry and free flight)	17,823	75,153
TERCOM updates	77	308
Free flight	48	141
Captive	29	167
DSMAC updates	--	71
Free flight		40
Captive		31

[a] Through 7/31/82.

Table C.3

KEY AGM-109 AND BGM-109 TEST FLIGHTS

Number	Date	Objective	Results
3	3/28/76	Integration of missile-engine-guidance	First flight test with a jet(J402) engine
6	6/5/76	Integration of missile-engine-guidance	First integration of the airframe with the F107 engine and CMGS with TERCOM updates
8	7/16/76	Navigation, TERCOM update, terrain following	First demonstration of terrain following
13A 13B	9/28/76 9/30/76	Simulated operational mission	First demonstration of total land-attack capability
16	12/7/76	OTH, anti-ship search	First demonstration of OTH, and anti-ship search capability
17	1/29/77	Navigation, TERCOM, terrain following, and SMAC	First missile test of the SMAC system to reduce missile CEP
19	2/24/77	Transition from boost-to-cruise engine flight	First demonstration of boost-to-cruise engine flight and canister launch capability
22	6/20/77	Underwater launch, anti-ship search	First transition of underwater launch-to-boost-to-sustainer engine
--	10/25/77	Parachute test, air drop	First successful REM parachute system test
23	1/7/78	Survivability demonstration	First survivability demonstration flight
24	2/2/78	Sub launch, transition to cruise flight	First launch of a full-up vehicle from a submarine

Table C.3

Continued

Number	Date	Objectives	Results
28	4/24/78	IR survey	Second ground launch; first of a land-attack missile
29	5/26/78	Airfield attack mission	First demonstration of TAAM (with SMAC update)
38	2/14/79	Sub-launch validation, sealing and pyro system verification	Demonstration of sub-launch of a TASM at a specified depth and speed, proper functioning of the sealing and pyrotechnic systems, and transition to cruise flight
40	4/13/79	Ground launch, seeker, and PI/DE development	First TASM test of the PI/DE system
43	6/28/79	OTH anti-ship search	First launch using the MK-117 Fire Control System
44	7/17/79	Case I (modified) navigation profile	First AGM-109 free flight and rotary rack launch
49	9/8/79	Aero performance	First AGM-109 launch from a B-52 pylon
50	9/13/79	Vertical launch, seeker evaluation	First vertical launch
59	3/13/80	Tomahawk/ABL compatibility	First launch from an Armored Box Launcher
60	3/19/80	Tomahawk/ship/IWCS/ ABL compatability	First launch from a surface ship
61	5/16/80	TEL launch, DOE W84 launch and flight development	First launch in the GLCM program

Table C.3

Continued

Number	Date	Objectives	Results
62	6/6/80	PAV sub-launch, cruise flight, and shaped trajectory sequencing	First sub-launch of a Production Air Vehicle, and shaped trajectory sequencing
65	11/26/80	VLS launch	First launch from the Vertical Launch System (on land)
67	1/15/81	Anti-ship search, acquisition, and target hit	First DT/OT program flight, first TASM DT/OT program flight, and first target hit
70	2/15/81	DSMAC block I test	First fully configured conventionally armed land-attack mission
72	3/28/81	Sub launch, full mission demonstration	First sub launch of a LAC flight
73	7/10/81	First full land-attack mission	First land-attack SLCM target hit
74	7/30/81	DT/OT of conventionally-armed land-attack SLCM	First land-attack SLCM DT/OT program flight
76	9/19/81	DSMAC/illuminator night-time performance demonstration	First known night flight of a cruise missile
87	7/18/82	Live warhead, anti-ship missile	First ship sunk by an extended range cruise missile

ALCM TEST PROGRAM

The ALCM is currently in the advanced stages of DT&E and OT&E (actually FOT&E), as it has passed the decision Milestone III. The overall test program is summarized in Fig. C.2. The ALCM DT&E/FOT&E Program consisted of 19 free flights conducted between April 1980 and December 1981. These flights constituted Phase II and III of the follow-on test activity. The B-52 cruise missile integration launch phase (Phase II) consisted of 11 launches. The (B-52) Offensive Avionics System (OAS) prototype availability for ALCM launches marked the beginning of Phase III of the ALCM follow-on testing. That phase provided eight launches as a part of the OAS IOT&E. Phase IV of the ALCM follow-on testing, running from January 1982 through December 1982, will be conducted by the Air Force Test and Evaluation Center (AFTEC) and the Strategic Air Command (SAC) test crews for the ALCM-OAS operational test and evaluation. It will conclude with the weapon system IOC.

The testing conducted on the ALCM during Phase I (ALCM Competitve Flyoff, described in Appendix D) was a combined DT&E/IOT&E. Each missile system contractor flew ten flights, the last seven of which were launched by AFTEC aircrews. Air Force personnel performed "hands-on" and "over-the-shoulder" maintenance on the system under test. The data collected during the competition were applicable to both developmental and operational evaluations. The AGM-86B and the AGM-109 were evaluated to verify specification compliance for range, performance, navigational and terminal accuracy. Limited data were collected on terrain following segments and enroute and terminal accuracies. Phase II and III missions are designed to expand that data base. In addition, assembly, maintenance, checkout, and loading were also evaluated. The mission planning function is under evaluation for adequacy and completeness.

The OT&E during the flyoff addressed the operational effectiveness including survivability and suitability of the ALCM System to varying degrees. Due to inadequate data, some areas of the evaluation were undetermined or evaluated with only a low confidence level.

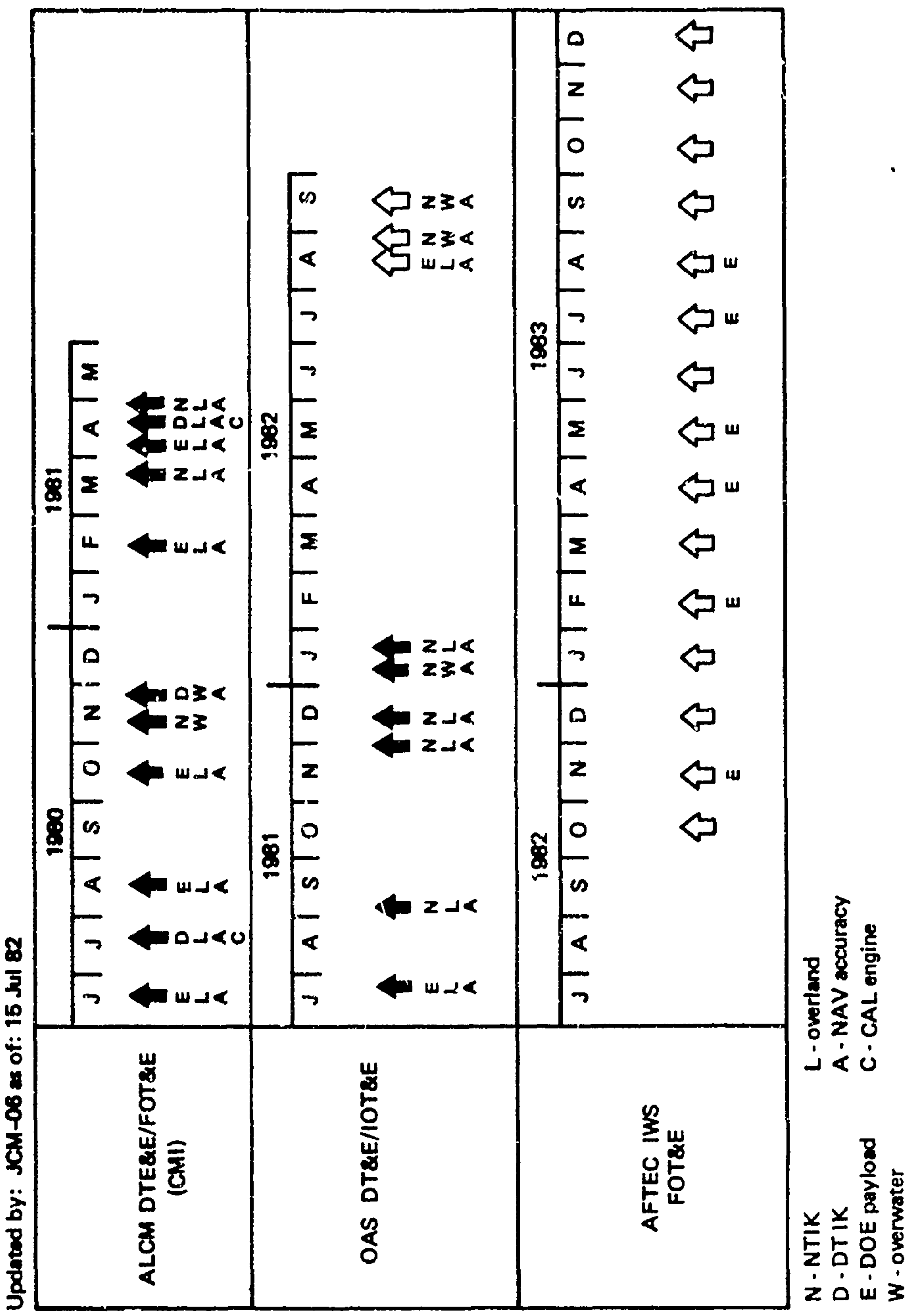

Fig. C.2 -- ALCM flight test schedule

The current DT&E/FOT&E planning encompasses the critical areas that remain unanswered, generally in the area of cruise missile performance, and include enroute and terminal accuracy, terrain following, and the flight launch envelope. Mission planning, untested support equipment, technical orders, and TERCOM map accuracy are also areas of concerns. Typical mission scenarios with production representative hardware and software will be simulated and demonstrated in the DT&E/FOT&E and will support mature system projections that AFTEC will provide to the using command.

A summary of the critical ALCM operational T&E issues is given in Table C.4.

Table C.4

ALCM CRITICAL T&E ISSUES

1. Adequacy of ALCM performance and weapon system reliability test data
2. ALCM/B-52G weapon system integration
3. ALCM FOT&E performance
4. Mission Planning and DMA data support for First Alert Capability (FAC) and Initial Operational Capability (IOC)
5. Availability of support equipment and technical data to meet FAC and IOC milestones
6. OT&E must be performed in the following areas:
    A. ESTS Test Package Sets
    B. Munitions handling equipment
    C. System Interface Test
    D. Missile Interface Test
    E. Missile Storage Reliability

Product Acceptance Testing

The ALCM PAT&E conducted on each missile begins with a passive continuity test, and if successful it is followed by using an Electronic Systems Test Set for a level I factory acceptance test of the missile. The level I test identifies "gross system errors and isolates the malfunctioning component." If necessary, a

> level II test is run to isolate the fault to a specific component. With replacement of the malfunctioning unit, level I testing is then restarted from a point prior to the original fault detection and continued to completion or next malfunction. By this means, all systems are tested and out-of-tolerance packages replaced until factory acceptance testing meets the criteria of the ALCM Test Plan. Combined environments reliability tests will also be accomplished on selected missiles."[1]

GLCM TEST PROGRAM

The GLCM flight test program consists of three contractor test and evaluation (CT&E) and seven DT&E/IOT&E flights. Data from the flight test program will be used to evaluate the launch performance, the effects of the GLCM-unique features of the SLCM missile, and to evaluate mission performance capabilities for the expected operational GLCM scenario. In addition, missile subsystems will be monitored to ensure no functional degradation from AGM-109 and SLCM flight test results.

GLCM DT&E to date has centered on camouflage, hardened shelter, trailer mobility, and tractor/trailer engineering tests. Since the GLCM is derived from the (nuclear-armed land-attack) SLCM, that program has been tasked to provide a qualified missile. In addition, some data applicable to the GLCM were obtained using the AGM-109 during the ALCM Flyoff Test Program. Missile related data input to the GLCM program includes that in engine qualification, cruise missile guidance system qualification, aerodynamic performance, terrain following, and launch performance.

At the time the GLCM TEMP was prepared, there had been no formal

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[1] *ALCM T&E Master Plan*, March 26, 1980.

operational testing of the GLCM weapon system, although the first Air Force controlled DT&E/IOT&E test flight was in June 1982. Some operational testing, including dynamic survivability testing, had been conducted by AFTEC with the AGM-109 air vehicle during the ALCM competitive flyoff.

The JCMPO conducted the initial in-flight survivability testing that ran from Jaunuary 1978 to November 1979, during the ALCM flyoff. Ten test flights were flown with the AGM-109 against various simulated airborne and ground defensive threats to obtain generic detection and tracking data. A live firing program utilizing surface-to-air and air-to-air missiles was conducted against cruise missile-sized target drones. Further survivablity testing is a part of the current ALCM OT&E programs. Refined procedures and enhanced instrumentation will be used for those tests.

A summary of the critical GLCM technical and operational T&E issues is given in Table C.5.

Product Acceptance Testing

Data for the GLCM PAT&E will be derived from FFAT and Q/RST for the missile, Transporter Erector Launcher (TEL), and Launch Control Center (LCC); and LCC and Warranty Verification Tests (WVT) for the missile.

The objective of the GLCM FFAT is to assure that the

> weapon system production components or prime items demonstrate the capability to meet specification requirements prior to official Government acceptance. Satisfactory completion of these tests will provide initial certification of missile operational capability at the start of the specified warranty period.

The objective of the GLCM Q/RST is to assure that "the GLCM weapon system production components or prime items continue to meet specification reliability and performance requirements. These tests will be performed on a sampling basis and will include storage and worst-case environment mission simulation tests."

Table C.5

GLCM CRITICAL T&E ISSUES

Technical Issues	Operational Issues
Fiber Optics	Mobility
Mobility	Reliable Communications
General systems capability	Navigation and Terrain Following
Weapon Control System	Compatibility/Interoperatbility
Mission Planning System	Security
Nuclear Warhead	System Safety
Environments	Supportability
	System Availability
	Human Factors
	Survivability

The objectives of the GLCM WVT are to

> determine that the warranted GLCM missile is meeting the specified missile performance and reliability requirements of the contract. Periodic GLCM operational launches will be conducted in order to measure the missile warranty flight guarantee requirements. In addition, environmental/mission simulation tests are to be performed on operational assets in order to measure the missile warranty flight guarantee requirements. Every missile that is returned to the contractor facilities will be tested to measure the missile warranty missile readiness/reliability guarantee performance.

MRASM (AGM-109H) TEST PROGRAM

As in the GLCM case, some performance data collected during previous SLCM and AGM-109 flight tests are applicable to the MRASM DT&E program. To maximize the utility of limited assets, the T&E program will combine CT&E, DT&E, and IOT&E into a single integrated test plan.

A Combined Test Force will be formed to manage the integrated test program. In the early tests, the primary objectives will be to combine CT&E objectives with any DT&E/IOT&E objectives that can be completed without interference. The contractor will accomplish a large portion of the testing functions in the earlier tests with the government assuming responsibility for these functions as testing proceeds. Air Force personnel will assume nearly all of the test function by the time most of the DT&E objectives have been completed, with the contractor assisting as necessary.

Generic cruise missile survivability testing will contribute to the MRASM OT&E data base. There has been no specific MRASM OT&E to date. IOT&E of the AGM-109H will be conducted as part of a combined DT&E/IOT&E test phase. Operational testing may continue beyond the planned production decision date (February 1985) depending on how many of the IOT&E objectives have been met.

IOT&E captive-carry and free-flight tests using production-representative missiles will be conducted to verify operational effectiveness. Following early free-flight tests in which Air Force and other government personnel progress to the complete assumption of testing, the Air Force will conduct free-flights with simulated and live runway attack missions using inert, mass simulator, and live submunitions to evaluate centerline and off-axis attack modes and impact patterns. Operations and Supportability demonstrations and ground/environment testing will use dedicated test articles. Handling, transportation, and organizational maintenance procedures will be evaluated during air vehicle movements to test sites and air vehicle preparations and flight test routines.

Requirements for the MRASM FOT&E will be finalized following IOT&E. The MRASM FOT&E will be conducted, where necessary, to resolve system deficiencies identified during previous testing or to develop and test system pre-planned product improvements (PPPI). Changes to operational flight programs will be evaluated during SAC-conducted FOT&E.

A summary of the critical MRASM (AGM-109H) technical and operational T&E issues is given in Table C.6.

Table C.6

MRASM (AGM-109H) CRITICAL T&E ISSUES

Technical Issues	Operational Issues
DSMAC Performance	MRASM Operational Planning System Effectiveness
MRASM Missile/Carrier Aircraft Software Compatibility	Carrier Aircraft Pre-launch Accuracy and Interoperability
Engine Reliability Using JP-10 Fuel	MRASM and Carrier Aircraft Survivability
MRASM Mission Planning System Capability	Adequacy of Missile to Reach Submunition Release Points
Submunition Performance	Mission Effectiveness
	Capability of Satisfying User Supportability Requirements

Product Acceptance Testing

Data for the MRASM PAT&E will be derived from FFATs, component/subsystem Qualification Tests (QTs), Reliability Sampling Tests (RSTs), and WVTs of the missile. The program will be structured similarly to that of the SLCM program, and where appropriate, modifications to the ALCM approach will be made to accommodate the unique MRASM weapon system requirements. The FFATs will be conducted by the applicable contractor on a to be decided basis to "demonstrate the capability of the MRASM weapon system production components or subsystems to meet specification requirements prior to official government acceptance of the item." Satisfactory completion of these tests will "provide initial certification of missile operational capability at the start of the warranty period." Component Q/RSTs will be conducted to "ensure that the MRASM weapon system production components/subsystems continue to meet specification reliability requirements." These tests will be performed on a sampling basis and

will include storage and environment mission simulation tests. The MRASM weapon system WVTs will be conducted to verify that MRASM is meeting the specified missile performance and reliability requirements of the contract. Periodic MRASM operational launches will be conducted to measure the missile warranty flight guarantee requirements. As in the GLCM case, every missile that is returned to the contractor facilities will be tested to measure the warranty missile readiness/reliability guarantee performance.

CRUISE MISSILE TERCOM AND SURVIVABILITY FLIGHT TESTS

The following subsections provide a brief examination of the flight testing conducted to verify cruise missile accuracy and survivability. Additional material relating to DMA TERCOM and terrain following product preparation and testing in support of the cruise missile program is given in Appendix B.

Considerable TERCOM flight testing was performed in aircraft before its use in a cruise missile flight. It was also necessary, however, to develop inland ranges (from the Pacific Missile Test Center at Point Mugu, California to the Tonopah Test Range, Nevada, and to the Dugaway Proving Grounds, Utah) to permit complete CMGS evaluation for land-attack cruise missiles. The development of these inland test ranges proved to be a lengthy process, in part because they were the first such ranges ever developed by the Navy. To assist in future cruise missile T&E programs, the JCMPO is attempting to establish test ranges on the East coast to test anti-ship and land-attack SLCM variants. Similarly, the dynamic survivability test program was the first such program undertaken for an aircraft or cruise missile. Although dedicated survivability missions were flown for land-attack cruise missiles, the anti-ship survivability tests were combined with engineering development tests to reduce T&E costs.

TERCOM Flight Tests

Terrain Contour Matching flight testing began in the mid-1960s in support of Air Force Maneuvering Reentry Vehicle studies. The contractor, E-Systems, flew numerous aircraft test flights that demonstrated a considerable reduction in navigation error. While under

contract to the Navy Cruise Missile Project Office, E-Systems flight tested a TERCOM breadboard system onboard an A-7 aircraft. It permitted inflight utilization of the update information to compensate for the existing navigation errors. The resulting test flights were highly successful, as the TERCOM Aided Inertial System permitted the A-7 aircraft to fly a closed loop over 1,000 miles and return on target.

Convinced by these results, the Navy Project Office issued a Request for Quotation for competitive prototyping to develop the best land-attack cruise missile guidance set (including TERCOM) at the lowest cost. Four responses were received on May 6, 1974, including those from E-Systems, GD/C, MDAC, and Vought. Of these four competitors, only E-Systems had been under contract up to that time for TERCOM development, while the other three contractors were also competitors for the SLCM airframe.

In June 1974, E-Systems and MDAC were awarded competitive demonstration contracts for a land attack cruise missile guidance system. A flyoff was performed between these contractors in a C-141 aircraft, under the jurisdiction of Air Force and Navy personnel, and MDAC was selected as the land-attack guidance contractor in October 1975. During the closed loop test flights, the MDAC integrated land-attack guidance system demonstrated accuracies as good as or better than those specified by potential Air Force and Navy users.

Since that time, several thousand TERCOM aircraft flight tests have been performed by MDAC to test the performance and reliability of the cruise missile land-attack guidance system. The results of these tests, performed over a wide variety of geographical locations and seasons, indicate that the TERCOM concept, as implemented in the land-attack guidance system, is sound. With successful TERCOM accuracy and reliability characteristics in hand, attention was then turned to developing operational TERCOM reference map production procedures and testing candidate terrain elevation data types that could be used to produce more economical TERCOM maps. The highly successful nature of the TERCOM test program was in part due to the interaction between the Defense Mapping Agency, the JCMPO, and MDAC. A discussion of this relationship is given in Appendix B.

In an effort to evaluate the effect of seasonal changes on TERCOM performance, many tree-covered TERCOM test sites have been used.

> The analysis of E-Systems results (1973-74) showed no significant seasonal effect. Analysis of MDAC Alabama data (1974) showed no significant difference in noise level between bare and tree-covered terrain. Analysis of MDAC tests in Northwest Missouri (1977) yielded occasional instances where isolated and sparse trees were missed in DMA reference data, but the noise levels were low and good TERCOM fixes were obtained in all cases. The Boeing TERCOM flight tests using a T-33 testbed aircraft have produced similar results. In fact, no false fix has ever been attributed to a foliage effect in the cruise missile program. Furthermore, with updates based on voting three TERCOM fixes, there has never been a false *update* (due to any cause) in the cruise missile program.[2]

At the present time, there has never been a false TERCOM *three fix* update within the cruise missile test program, although several individual false TERCOM fixes have occurred.

Cruise Missile Survivability

Cruise missile survivability is based upon a number of factors, including: low observables, sophisticated terrain following navigation, mission planning to avoid defenses, and the large scale deployment possible because of relatively low unit costs. Visual, infrared, noise, and radar observable considerations were incorporated into the initial cruise missile design. Furthermore, the design process has been coupled with static and dynamic flight testing during the advanced and full scale engineering development phases of the Air Force and Navy cruise missile programs to ensure that acceptable observable charecteristics would exist before deployment.

The initial approach used in the test program was to study existing and potential enemy threat capabilities, optimize cruise missile design for survivability, generate analytical models, conduct flight test assessments of the candidate ALCMs, and--based upon these results--

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[2] Department of Defense Appropriations for 1980, Hearings before a subcommittee of the Committee on Appropriations, House of Representatives, April 30, 1979, pg 552. Supplemental Submission from Rear Admiral Walter M. Locke.

upgrade the analytical models and cruise missile vehicle design.[3] The cruise missile survivability program was to be split into two phases. The first phase would assess the post-launch cruise missile survivability against a spectrum of current and potential enemy threats, identify critical threat systems to the cruise missile, and collect quantitative data to upgrade the analytical models. The second phase (IIA) would provide an in-depth examination of critical threat systems identified from Phase I, and include comparisons of the contractor's candidate ALCMs, the AGM-86B and AGM-109 (IIB).[4] The rationale for performing flight tests was in part to upgrade existing analytical models and provide validation data for them. This was necessitated by the complex interaction of the low cruise missile observables with ground clutter and terrain masking, which reduced the reliability of model estimates in some cases. The Phase I tests were envisioned to help in the design of the remainder of the Phase II development and operational survivability tests. This was necessitated by the lack of dynamic survivability flight tests and the reliance on static cruise missile ground test data to this point.

The Phase I testing occurred between January and October 1978, with seven land-attack Tomahawk cruise missile flights at the Nellis Test Range, the White Sands Missile Range, and the Pacific Missile Test Center. In these tests, U.S. systems were used as surrogates for Soviet air defenses that might be deployed in the 1980s: early warning/ground control intercept radars, radar and infrared surface-to-air and air-to-air missile sensors, anti-aircraft artillery radars, airborne and ground-based radars, and current and look-down shoot-down fighter aircraft.

Results from the Phase I tests indicated the effectiveness of airborne interceptor and surface-to-air missile air defense systems. Those test were critical because a poor performance by the cruise missile could have adversely affected the entire program. During the

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[3] Hearings on Military Posture and House Resolution 10929, Department of Defense Authorization for Appropriations for Fiscal Year 1979, Committee on Armed Services House of Representatives, p. 253, February 24, 1978.

[4] Ibid., p. 254.

course of the tests, it became clear that the governing physics were quite complex and that there were no simple answers to questions such as cruise missile detection because of the complex interaction of the missile observables, terrain, and viewing geometries. The flight test data were examined in detail, and often the results did not match those expected from some prediction models.

The Phase II program was originally envisioned to include the technical and operational survivability evaluation for the SLCM. After the decision to proceed with an ALCM competitive flyoff, a comparative survivability program between the AGM-86B and the AGM-109 was split off (Phase IIB), although results were not used in the ALCM source selection process.

Discrepancies between the Phase I cruise missile flight test data and analytical model predictions had two effects on the Phase II program. First, the objectives of the Phase IIA survivability testing were modified to continue the Phase I activities but to include the evaluation of cruise missile prelaunch survivability, cruise missile infrared signature characteristics, nuclear vulnerability considerations, and surface-to-air and air-to-air missile end-game performance.[5] Second, a finer level of testing was planned and performed during the Phase II program to explore factors such as missed observations by the participating systems in the Phase I program.

Two Phase IIB flights were performed per contractor during the ALCM competitive flyoff at the Utah test range to obtain dynamic survivability data on ALCM vehicles. The rationale for including this area in the ALCM flyoff was not for source selection purposes, but to understand better the dynamic survivability characteristics of both contractor's candidate vehicles (hence the ALCM that would eventually be selected and deployed).

SLCM test flights were also performed during the Phase II program to provide dynamic survivability data on the anti-ship and land-attack versions. Because of the antennas required for testing purposes, a parachute door for the REM, and other test-related differences, the

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[5] Department of Defense Appropriations for 1980, Hearings before a subcommittee of the Committee on Appropriations, House of Representatives, April 30, 1979, p. 608.

radar cross-sections of the cruise missiles tested were greater than those for production missiles. Consequently, test results were conservative, at least for a given radar, terrain, and viewing geometry.

Partly because of discrepencies that still exist, a proposal for continuation of the Phase II program is under evaluation. If approved, a near-term survivability assessment will be conducted, together with a longer-term resolution of survivability assessment issues.

Appendix D
ALCM COMPETITIVE FLYOFF

Despite the January 1977 DSARC II Decision Memorandum directing only the Air Force ALCM be developed for air launch, interest continued within OSD, the Congress, PMA-263 (later JCMPO), and GD/C to pursue an air-launched SLCM variant (referred to as the Tomahawk Air Launched Cruise Missile [(TALCM, or AGM-109)]. It was clear that both the GD/C and Boeing candidate missiles would not be produced for this role because of cost and logistical considerations. The GD/C AGM-109 held an advantage in that the SLCM, from which it was derived, had 14 flight tests launched from an A-6 aircraft prior to DSARC II. Although the Boeing ALCM-A (AGM-86A) had flown before, the ALCM-B (AGM-86B) was still a paper design at that point. The AGM-109 design, moreover, was very close to that of the nuclear-armed land-attack SLCM, so AGM-109 development costs were expected to be considerably lower than that for the AGM-86B. In addition, since both the SLCM and the newly created GLCM showed promise of advancing to the production phase, the GD/C AGM-109 had the potential to be less expensive than its Boeing counterpart because of larger production quantities.

In Boeing's favor was the fact that all six of their AGM-86A flights had been "cold launched" from a B-52; that is, the sustainer engine was ignited after the missile was dropped from the B-52. In the air-launched SLCM tests, the engine was fired before the missile was released from the A-6. Consequently, Boeing had an apparent advantage in terms of "cold launching," its ALCM (the operational launch method), and in understanding the separation dynamics between the missile and the B-52. Another advantage that would later weigh heavily in Boeing's favor was its understanding of the B-52, the SRAM and SRAM rotary rack, and the integration of this missile/bomber combination. General Dynamics had no experience with the B-52, although they did have an understanding of SRAM integration on its FB-111. A final Boeing advantage was its understanding of the Stra' ic Air Command (SAC) (the eventual air-launched cruise missile cust through their experience

as prime contractor on the B-52, SRAM, and AGM-86A programs. That gave Boeing, among other things, an understanding of SAC logistics and test procedures. Although General Dynamics had similar experience in the FB-111 program, it was less than Boeing's and limited to its Fort Worth division.

In response to a question from Mr. John J. Ford on September 9, 1977, Captain Locke provided the following written response regarding the necessity of holding the ALCM competition:

> The disadvantages are primarily related to cost and schedule risk. The maintenance of competition through Full Scale Engineering Development should insure that the government is offered the best system possible for the lowest cost. The fact that the forces of competition will be in effect at the time that validated production proposals are submitted should offset the cost and schedule risk inherent in the concurrency required by the desired IOC. If a single contractor were chosen now the government would be forced to "buy before fly" since the ALCM-B and Tomahawk (AGM-109) have not demonstrated their system effectiveness from the B-52 to date. Both these long range cruise missiles require development of new launch racks and pylons and must be integrated into the B-52 Avionics Suite. In view of the increased national emphasis now placed on the cruise missile as a part of the Strategic TRIAD, resorting to one contractor for sole source procurement prior to completion of the above development effort could result in significant cost or schedule risk....The flyoff will result in a demonstration of system effectiveness and a proposal for production from each contractor. This should provide the data required for the Department of Defense to choose the best possible system for the Air Launched mission at the lowest possible Life Cycle Cost under minimum risk conditions. Both systems will be required to meet common specifications and operational requirements.[1]

Additional justification for the competitive flyoff was offered by Captain Locke and Dr. William Perry at congressional appearances during July and September 1977. One factor mentioned[2] was that the competition

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[1] Hearings on H.R. 8390, Supplemental Authorization for Appropriations for FY78, Committee on Armed Services, House of Representatives. Statement of Captain Walter M. Locke in response to questions submitted by Mr. John J. Ford, Director, House Armed Services Committee Staff, September 9, 1977, pp. 284-285.

[2] Hearings on S. 1863, Fiscal Year 1978 Supplemental Military Authorization, Committee on Armed Services, United States Senate. Written response to questions submitted by Senator Thomas J. McIntyre, July 29, 1977, p. 106.

would require each contractor to demonstrate its capabilities and performance through the stages of preliminary production. That approach might provide valuable insight as to how well each contractor could transition from a development program into pilot production before a commitment was made to a single missile. A second factor discussed[3] was that if a paper competition was staged, one contractor could not be named the winner without the risk of the other immediately filing a protest. It was stated that at least a paper source selection would be necessary to avoid a protested decision, although that might not provide enough information to determine which missile was best suited for the ALCM role.

The formal competition between the two companies was announced on September 30, 1977. In his memorandum to the Secretaries of the Air Force and Navy, Dr. Perry stated that: "It was a matter of the highest national priority, especially in light of the B-1 decision, to develop an ALCM with optimal performance, and minimum cost and schedule delays." He ordered a competitive flyoff between the Boeing and GD/C candidate cruise missiles (designated AGM-86B and AGM-109, respectively) to determine which one would be procured. He further ordered that the ALCM competition be conducted by the JCMPO (which would at least be retained through the ALCM DSARC III), and include operational tests with SAC crews. Finally, he specified the structure of the Source Selection Advisory Committee (SSAC), and nominated the Secretary of the Air Force to be the Source Selection Authority (SSA) who would determine the outcome of the competition.

Table D.1 compares the two missile designs.[4] The radar altimeter has been deleted from this table as the current missile radar altimeter is different from the original unit specified (APN-194). In addition, the target loading process used in both missiles, although different at that time, later became the same. A bulk memory element onboard the

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[3] Hearings on the Department of Defense Appropriations for 1978, Subcommittee of the Committee on Appropriations, House of Representatives, September 20, 1977, p. 330.

[4] Hearings on House Resolution 8390, Supplemental Authorization for Appropriation for Fiscal Year 1978, Committee on Armed Services, House of Representatives, September 9, 1977, p. 280.

B-52 would be used for multiple mission storage, with individual missions electronically transferred to each missile before launch.

The major contractors involved in the ALCM flyoff included: The Boeing Aerospace Company (BAC), General Dynamics/Convair Division (GD/C), McDonnell Douglas Austronautics Company (MDAC), Williams International Corporation (WIC), and The Boeing Military Airplane Company (BMAC). BAC was the prime contractor on the AGM-86B, and GD/C was the air vehicle prime contractor on the AGM-109. MDAC was the guidance prime contractor on the AGM-109, providing all guidance hardware and software, while also supplying the INE and the radar altimeter for the AGM-86B.[5] The WIC F107 engine was provided to BAC and

Table D.1

AIR LAUNCHED CRUISE MISSILE COMPARISON[a]

Factor/Subsystem	AGM-86B	AGM-109
Gross weight (lbs)	2827	2553
Length (inches)	234	219
Wing area (sq ft)	11.0	12.0
Wing sweep (degrees)	25.0	0.0
Fuselage cross section	Triangular	Circular
Warhead	W-80	W-80
Environmental control	Air cooled	Fuel cooled
Stabilization/control	2-axis	3-axis
Navigation/guidance	P-1000 platform LC 4516-C computer LCM 9000 memory (32K)	P-1000 platform LC 4516-C computer LCM 9000 memory (64K)
TERCOM (and terrain following)	Boeing software	MDAC software
Propulsion (F107 engine)	Accessories on bottom	Accessories on top

[a] The data in this table were based on early ALCM estimates. The March 1982 SAR for the AGM-86B shows an air vehicle weight of 3175 lb and a length of 249 in. Similarly, the March 1982 SLCM SAR shows an air vehicle weight (at start of cruise) of 2584 lb for the nuclear armed land-attack missile. Only a small weight difference should exist between that missile and the AGM-109.

GD/C as government furnished equipment (GFE), although the engine was packaged somewhat differently to accommodate variations between the two air vehicle designs. BMAC was added to the flyoff to provide B-52 integration expertise for both air vehicle prime contractors. Since BAC was a sister division of BMAC and had launched all of their AGM-86A flights from a B-52, it already had considerable experience in that area.

SOURCE SELECTION PROCEDURES

The JCMPO developed tentative source selection criteria in July and August 1977 for a competition between the GD/C and Boeing designs, although this process did not become formalized until after a proposal solicitation letter was released by the Air Force on September 27, 1977.

On April 8, 1978, the ALCM Source Selection Plan (SSP) was signed by General Alton Slay (Commander, Air Force Systems Command) and fowarded for approval to Mr. John Stetson, Secretary of the Air Force. The SSP contained detailed information pertaining to (among other things) the source selection schedule and chronology, proposed SSAC and Source Selection Evaluation Board (SSEB) membership, and evaluation and source selection criteria. The criteria were grouped into three categories: operational design and utility; adequacy of program; and production and remaining RDT&E contract costs. Factors considered in the operational design and utility category included: survivability, operability ("does it work"); accuracy and time control; mission preparation; life cycle cost (including cost realism); and range (above the minimum specified value). Factors considered in the program adequacy category included: program management; integrated logistics support, configuration management, production/manufacturing; engineering; system test; life cycle cost/design cost implementation; and data management.

On July 12, 1978, Mr. Stetson approved the submitted SSP, and the suggested membership and advisors for the SSAC. On July 17, 1978, General Slay submitted a modified plan that included changes due to

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[5] MDAC also supplied the TERCOM software to BAC, but other software used on the AGM-86B (e.g., terrain following) was developed by BAC. See footnote 1, Appendix B for additional information.

(then) recent EXCOM and DoD decisions, including the deletion of accuracy goals from the ALCM source selection competition, and addition of a Leader/Follower procurement approach as an acquisition option for the production phase. From that point through the end of the ALCM competition, BAC and GD/C had to address management strategies and pricing for both sole source and Leader/Follower production options (discussed below).

On August 4, 1978, Mr. Stetson and Dr. Perry were briefed by General Slay and Rear Admiral Locke on the ALCM source selection procedure. The proposed program would consist of a pilot production of 12 and 18 missiles for FY78 and FY79 (respectively) for each contractor, and a program covering ten flights per contractor. Production quantities of 263 and 690 missiles for FY80 and FY81 were scheduled for the winning design. (This was later changed to 225 and 480 for FY80 and FY81, respectively.) The SSAC chairman was to be General Slay, and the SSEB chairman was to be Colonel Alan Chase. The flyoff between contractor missiles was scheduled to begin in June 1979 and run through November 1979. The source selection was scheduled for January 1980, and the DSARC briefing (for the winning design) was to be held in February 1980.

The ALCM source selection process entailed the following items. First, the SSAC was to approve the criteria weights of the SSP. Standards were to be prepared before the receipt of proposals from the two contractors in response to a request for proposal (RFP). Contractor proposals they were to be evaluated and best and final offers (BAFO) submitted by the contractors to the negotiation team. Both contractors would then perform their ten allocated test flights.[6] The SSEB would then prepare a summary analysis report and submit it to the SSAC including information on each of the previous items, and a comparision of each proposal to the appropriate standard. The SSAC would then compare proposals and formulate a report for the SSA comparing the two contractor proposals. The resulting SSA decision selecting a winning contractor would then be followed by a production contract award to that company.

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[6] A BAFO was used to define clearly the end of the proposal phase for both air vehicle contractors.

On December 22, 1978, an RFP was issued to BAC and GD/C for the ALCM. That was approximately five months after the SSP was approved and approximately three months after the SSAC assigned the criteria weights.

In January 1979, a Solicitation Review Panel (SRP), established by the Air Force Systems Command to evaluate the ALCM FY80 and FY81 production buys, formulated a series of concerns associated with the source selection strategy. In the first of these, dealing with support equipment (SE), the SRP recommended that only identified SE be priced in the BAFO; unidentified SE should be procured by provisioning techniques, and the contractor should recommend a quantity of identified SE. That strategy (later incorporated) would provide flexibility for the government to change SE quantity without renegotiating the associated prices, hence potentially reducing procurement costs. Other recommendations included the approval of the contract ceiling of 120 percent for the ALCM FY80 and FY81 production RFP.

On February 5, 1979, the standards for source selection were prepared before receipt of the two contractors' proposals. The formal source selection began on March 5, 1979, with the receipt of technical proposals from each of the competitors.[7] The SSEB, composed of approximately 250 Air Force and Navy personnel, was then convened to evaluate the proposals. That portion of the source selection process consisted primarily of verification of the proposals to ensure that each competitior had correctly responded to the government's requirements. The competitors submitted the cost portion of their proposals on April 16, 1979, which were evaluated by the SSEB for realism and responsiveness.

On July 17, 1979, the first AGM-109 flight test occurred, followed on August 3, 1979 by the first AGM-86B flight test. On October 22, 1979, the two contractors submitted their BAFOs for the costing portions of their FY80/FY81 ALCM production costing proposals. The planned production program included 3418 total missiles through FY87 (this was later changed to 4348 missiles, as quoted in the December 1981 ALCM Selected Acquisition Report).

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[7] Department of Defense Appropriations for 1980, Hearings Before a Subcommittee of the Committee on Appropriations, House of Representatives, April 30, 1979, p. 532. Supplemental submission from Rear Admiral Locke.

On February 8, 1980, the tenth and final test flight of the AGM-109 was conducted, thus ending that portion of the ALCM competition. A summary of the flight tests for both contractors is shown in Table D.2. Each contractor flight tested one production ALCM during the competition to demonstrate the performance of procurement air vehicles. Two flights categorized as failures had early termination times. The failures due to software problems were readily identified and changed, as were those associated with hardware malfunctions.*

On March 25, 1980, BAC was selected as the ALCM competition winner and was awarded a fixed price incentive fee contract with a 9 percent profit margin and 120 percent ceiling. At that time, the option to use the Leader/Follower concept employing Boeing as the Leader and GD/C as the Follower for the FY83 buy was left open (see below).

In his decision memorandum dated April 30, 1980, Deputy Secretary of Defense Claytor passed the ALCM into production beginning with a 225 missile buy for FY80, leading to a minimum capability to produce 40 missiles per month thereafter. He also directed that follow-on testing be performed to evaluate fully the operational effectiveness and suitability of the ALCM, and that high priority reliability and maintainability efforts (with additional emphasis on storage reliability) be continued. Special attention was to be placed on improving manufacturing quality assurance discipline for this program, and warranties were to be implemented on ALCM airframe, guidance, and engine. (For a discussion of the resulting subsystem warranties, see Appendix H.)

Shortly after Deputy Secretary Claytor's decision memorandum was issued, the ALCM program began the transition process from JCMPO in Washington, D.C., to ASD at Wright Patterson Air Force Base, and by June 1980, that process was nearly complete. (Although the ALCM program was relocated to ASD, engine and guidance systems management was retained at JCMPO to ensure commonality between cruise missile variants.)

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* Boeing's tenth and final test flight crashed on January 22, 1980, because of a failure in the command override software. Since that was peculiar to the test configuration, it had no effect on the adequacy of the operational missile software.

Table D.2

AIR LAUNCHED CRUISE MISSILE FLYOFF SUMMARY [a]

Completed February 8, 1980	
20 Flights (54.1 hours total flight time)	
Results	
Successful	12
Partial success	6
Failures	2
Software	4
Hardware	4
Problems remedied	
19 flight follow on program (DT&E/FOT&E-12, OAS-7)	

[a] Hearings on Military Posture and H.R 6495, Department of Defense Authorization for Appropriations for Fiscal Year 1981, Committee on Armed Services, House of Representatives, March 3, 1980, p. 1821.

COMPETITIVE FLIGHT TEST PROGRAM

In any competition, the government is interested in the technical, cost, and management aspects of the proposals submitted. In this case, however, there was added emphasis on the contractor's understanding of how the missile would be interfaced with the B-52, including operations and maintenance considerations. Developmental hardware and software were produced that went well beyond the airframe itself to test each contractor's understanding of the total systems concept, including a flight control element, payload integration with the B-52, complete flight software preparation, carrier aircraft equipment modification, (SRAM) rotary rack modification, missile peculiar support equipment, air

vehicle integration, and associated data and training for each prime contractor.[9] Each contractor was required to build 12 production ALCMs for both FY80 and FY81 during the competition to support a first alert capability, and to test one in the resulting vehicle flyoff, thus provid ·· SSEB with an understanding of the contractor's capability to ·· rom building developmental to production vehicles. From this, ·ufacturing and quality control approaches for each contractor could be compared to determine if any important weaknesses were present before completion of the SSP and DSARC III.

Besides yielding data on missile performance, the flight tests were also to provide the SSEB with information related to the compatibility of each candidate ALCM with the B-52. Although removing the SRAM rotary rack from the competition would have saved money, it was retained to ensure that each contractor's ALCM could be successfully integrated and launched from the B-52, to maintain the pressure of the competition and to prevent giving credit by default to the contractors for this item. The B-52 offensive avionics system (OAS), however, was not available in time for the ALCM flyoff, although the B-52s used were otherwise the type that would be the best carrier aircraft for the deployed ALCMs. This situation did not affect the validity of the flyoff, because it was not intended to competitively evaluate the ALCM/OAS system. The flyoff did, however, demonstrate physical compatibility of the B-52/ALCM, including the rotary rack as well as the pylons.

At the time of the flight tests, not all support equipment common to the competing contractors was demonstrated, but those items were considered to be of a low risk and were purposely deleted to save funds. Similarly, because of a funding shortfall, the alternative B-52 that was to have been provided to each contractor was not available. The risk was considered low and acceptable in view of the costs involved in two additional aircraft. (During the flyoff, the two B-52s performed well, albeit with some problems in their onboard environmental control and radar systems.) Removing accuracy goals from the competitive flyoff was also not considered important, as the basic guidance hardware was supplied to the contractors as GFE and had been demonstrated in numerous

·. Hughes, "Competitive Options for the Medium Range Air ·sile," Masters Thesis, American University, 1981, p. 35.

previous cruise missile and captive aircraft flight tests by both Boeing and GD/C.

The flyoff program completion date slipped approximately three months during the course of the competition (from November 1979 to February 1980) because of the late receipt of the FY78 supplemental appropriation; bad weather, which hampered the chase/command aircraft which followed each ALCM flight; and delays in the flight test data reduction for the SSEB. Initially, the Flight Test Center at Edwards AFB could not process the ALCM flight test data quickly enough. In fairness to the personnel involved, the amount of data produced during the ALCM competition was greater than that generated on a per flight basis for any previous Air Force program (including the B-1). Although the turnaround for ALCM data reduction improved during the course of the flyoff, the time involved had not been adequately estimated at the beginning of the competition.

The ten BAC and ten GD/C test missions averaged 3.2 hours and 2.2 hours of flight time, respectively. Each contractor had four early termination flights; two of those for the Boeing were near the half way point of a typical four hour mission, and the other two and each of the AGM-109 early terminations occurred before the one hour mark. As a consequence, guidance and navigation test flight data were reduced below a desirable level, although adequate for the SSP and DSARC III. While overall ALCM guidance accuracy was an important consideration, previous flight testing in cruise missiles and on captive aircraft flights of the inertial navigation system with TERCOM had produced a large body of data demonstrating the desired performance levels.

One area where additional flight data was preferred involved the terrain following performance of each of the candidate vehicles at low altitudes. Aircraft flight tests could not provide a representative simulation of terrain following as in the guidance system accuracy case because of crew safety considerations, and differences in the aerodynamic performance and control system response between test aircraft and the candidate ALCMs. Although during the flyoff the flight tests were planned more aggressively with time to test the terrain following capabilities of the vehicles, a sufficient amount of low altitude terrain following data were available for SSEB analysis. This

was somewhat complicated by an early termination of the final AGM-86B flight and of AGM-109 flights seven and eight (although these terminations were not the result of terrain following mishaps).

COST CONSIDERATIONS IN SOURCE SELECTION

One of the benefits typically sought from a competitive development program is a reduction of unit flyaway costs (UFC) in the subsequent production phase. Such a reduction, of course, must be weighed against the additional cost of the second source during development.

Development costs initially estimated (on October 21, 1977) by the government for the AGM-86B and AGM-109 were $325.6 and $224.0 million (then year dollars) from FY78 through FY80.[10] The main cost differences between the two candidate vehicles were the airframe and to a lesser extent the guidance system. In the airframe case, the AGM-86B development cost was initially estimated to be $117.8 million higher than that for the AGM-109. This was in large part because the AGM-109 airframe was an incremental change from the SLCM, which was already under development, and the AGM-86B airframe was considerably different from the earlier BAC AGM-86A model. Guidance system cost differences were related to the interaction of MDAC with the two airframe contractors. In the BAC case, MDAC served as a subcontractor to supply guidance hardware only; in the GD/C case, MDAC also furnished the flight software. Engine, mission planning and other (support equipment) costs for the 2 contractors were initially estimated to be within 2 percent of each other for full scale development.

By the end of the ALCM flyoff, the cost for the competitive full scale development program for both the AGM-86B and AGM-109 had reached $730 million. Although inflation had contributed approximately $84 million to the cost growth, the remaining $96 million difference was caused by engineering changes, estimating errors, and delays in the test program.

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[10] Ibid., pp. 35-39.

Second Source Options

As early as April 4, 1978, ALCM production options were discussed at an EXCOM meeting. Two options were considered: sole source/winner-take-all (the plan at that time), and dual or co-production sources. There was a consensus supporting co-production, but no decision was made. At the next EXCOM meeting on May 12, 1978, the discussion was continued. The recommended approach used the Leader/Follower concept, with two options: (1) the loser of the BAC-GD/C competitive flyoff would become the Follower, or (2) to select the Follower competitively.

As a part of their proposals, each contractor was required to submit a plan for second sourcing the airframe to a potential Follower it were chosen as the competition winner.[11] Contract provisions were established to use one of three possible options: nominate the non-selected design contractor as the Follower, initiate a competitive Follower selection, or select no Follower. The baseline assumptions included were that the initial participants were limited to BAC and GD/C, the Leader company procurement plan would be an evaluation factor within the SSP, the commitment to production competition was only for the ALCM, and the Leader and Follower would produce identical vehicle designs.

The competition was limited to BAC and GD/C as potential ALCM airframe producers because both had an active land attack cruise missile program since 1972, integration and flight experience with engine and navigation systems, extensive understanding of the users maintenance and operational concepts and mission planning, and because it provided an arena for head to head competition between the contractors. Because BAC developed its own flight software package, and MDAC furnished this to GD/C, there was also an internal competition between BAC and the team of

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[11] The Leader/Follower concept was favored over a stand-alone Technical Data Package (TDP) because of potential problems in the accuracy of the data package (hence government liability), the large production investment necessary before any important problems might surface, and the possibility that the designs might diverge. This last factor might lead to a reduction in the commonality between ALCM airframes and, if GD/C won the competition, it might be even more critical because of the commonality between the AGM-109 and the GLCM and SLCM designs.

GD/C and MDAC in this area. This, however, was not an open competition within the flyoff, but one that would decide whether BAC or MDAC would be the ALCM guidance prime contractor, depending on who won the flyoff.

The basic contracting assumptions to be used in the Leader/Follower arrangement included: a prime/subcontractor relationship through the technology transfer process (using DAR 4-703[A]); FY82 would be the first fully competitive year between contractors; and incentives or penalties would be used to motivate the Leader in assisting the Follower during the technology transfer period.

During the DSARC III briefing, the Air Force argued that the Leader/Follower arrangement for dual sourcing the airframe was unnecessary. Competition already existed in the engine and guidance systems, dual sources had been established for the aluminum castings used in the ALCM airframe, adequate production capacity existed, using such an arrangement would have a potential for only marginal cost savings, and other integration and assembly contractors could be qualified later if necessary to reduce production risk. Deputy Secretary of Defense Claytor agreed with these arguments, stating in his decision memorandum: "This provides the necessary competitive environment in the major subsystems which comprise more than two-thirds of the missile's cost." He also specified that the Air Force should evaluate the application of Multi-Year Procurement (MYP) for the ALCM and present its recommendations to the EXCOM.

By choosing this route, the government was not liable to contractor protest, because the decision nullifying a Follower was an option specified in the RFP. Although the Leader/Follower option was not used in the production phase, its possibility served as a mechanism to spur contractor rivalry during the course of the competition.

In terms of potential savings from using a Follower second source in the production phase, several factors would have had to be considered. Air Force estimates indicate that the "up front" money needed to implement a Follower (for technology transfer) would have been on the order of $40 million. That could have been reduced or eliminated altogether, however, through the use of a capital investment incentive clause, as in the Tomahawk all-up round (AUR) competition. An additional concern would have involved the learning curve advantage that

Boeing would have held over the Follower. For example, if a 1-1/2 to 2-1/2 year technology transfer program had existed, Boeing would have obtained orders to produce approximately 1/6 to 1/3, respectively, of the total buy before the actual competition with the Follower began.

In the nuclear-armed land-attack SLCM case, the UFC decreased approximately 9.2 percent in FY82 after completion of the AUR second source agreements between contractors, but before the beginning of head-to-head competition. As in the ALCM, the engine and major portions of the guidance system hardware will be provided GFE to the contractors. If this value is representative of competitive cost reductions for the airframe and systems integration, then a total program cost reduction on the order of $70 to $90 million (FY82) may have been possible had the Leader/Follower dual sourcing approach been used at that time for the ALCM.[12] (This assumes, of course, that a capital investment incentive clause would have been used to negate the cost of technology transfer.)

If the Leader/Follower second sourcing approach was implemented at the end of FY82, Boeing would have obtained orders to produce approximately 1/2 to 2/3 of the total buy before actual competition began with the Follower, based upon a 1-1/2 and 2-1/2 year time to Follower qualification, respectively. Applying the same 9.2 percent decrease in UFC and the previous assumptions, savings on the order of $25 to 50 million (FY82) might be possible by using that acquisition strategy.[13] At this time, however, the government may achieve greater cost avoidance on this program by attempting to conclude the planned MYP than to initiate a Leader/Follower dual sourcing competition.

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[12] This estimate is in terms of FY82 dollars and does not include the effects of converting the savings over the length of the buy to a present value. The discounted savings would be lower than the range given, but the values shown here may well be a conservative estimate, as they do not represent head-to-head competition between the two AUR contractors. It is not possible to determine a more accurate estimate of the competition savings without knowing the appropriate discount rate and cost savings to use in the calculations.

[13] See footnote 12.

Multi-Year Procurement (MYP)

The initial production contract to Boeing was for Lot I (225 production missiles in FY80) with an option for Lot II (480 missiles in FY81). Lots III-V (480 missiles per year for FY82 through FY84) were then being considered for potential MYP. Preliminary Air Force savings estimates for using MYP for Lots III-V ranged from $50 to $70 million in then year dollars versus single year buys.

BAC had suggested a fixed price incentive contract for FY82 (Lot III) followed by a five year buyout. That alternative was viewed as being unsatisfactory because it was felt that Congress might not approve a five year buyout. Consequently, ASD asked Boeing to propose a MYP firm fixed price for Lots III-V. By April 1981, negotiations with Boeing were proceeding for Lot III, and ASD was considering the use of MYP for Lots IV-VI (FY83-FY85).

Other Cost Considerations

The criteria used for source selection were grouped into three major categories: operational design and utility, adequacy of program, and production and remaining RDT&E contract costs. Differences between the AGM-86B and AGM-109 engine and guidance systems were limited to packaging in the former, and packaging and software in the latter case. Although differences in guidance system cost would exist between the BAC and GD/C candidate vehicles because of the source of the flight software, the items with the greatest potential for competitive costing between contractors were the airframe and support equipment.

Cost credibility was a critical factor in the SSP. Contractor cost estimates were carefully evaluated by the SSEB for both their realism and achievability in the development program for flyoff items, and also for the relationship these articles would have with the proposed production design. In addition, government "Will Cost" teams made intensive investigations of actual costs of producing an item to make detailed comparisions between the contractor's actual versus estimated costs.

As previously mentioned, both contractors were also required to bid on furnishing *all* support equipment, even though they could not predict the quantity of equipment that would actually be needed. The approach used by the government was to have the contractors insert a series of price options in their proposals so that the Air Force could later select a specified quantity of support equipment without having to open up the resulting fixed price contract, a process that would undoubtedly have resulted in higher prices.

During the competition Boeing developed dual suppliers for the four cast main body tanks used in the AGM-86B. That was done at least in part to reduce cost by the use of competition between suppliers (hence to guard against monopoly pricing) and reduce production (schedule) risk. Although it is not possible to say what effect the strategy had on the ALCM competition itself, it was one reason cited by Deputy Secretary of Defense Claytor for not pursuing the Leader/Follower second sourcing approach in the production phase.

As in any competitive development program, it is difficult to estimate the degree of cost savings that may result due to the introduction of competition. Procurement savings for the AGM-86B would have to be at least greater than the development cost of the AGM-109 to justify the competitive flyoff from a purely financial viewpoint. In this case, however, developing an air launched cruise missile with "optimal performance, and minimum cost and schedule delays" were key factors given in Dr. Perry's September 30, 1977, memorandum that initiated the resulting competition. (A discussion of ALCM program costs is included in Appendix I.)

Appendix E
SUSTAINER ENGINE PRODUCTION COMPETITION

On January 14, 1977, the cruise missile program was authorized to move into full scale development, and the Joint Cruise Missiles Project Office (created at DSARC II) was directed to encourage second sources for cruise missile subsystem procurement. Second sourcing the F107 cruise missile engine, built by Williams International Corporation (WIC), was primarily of interest to minimize production risk. Although there was no reason to doubt the design or reliability of the F107 engine, the contractor was at that time a small privately owned corporation with no experience in high-rate production and whose maximum business was less than $40 million per year. The other reason later advanced for second sourcing the F107 engine was to attempt to reduce its cost through the use of competition. In July 1977 the JCMPO directed the F107 Joint Engine Program Office (JEPO) at WPAFB to conduct a study on which type of second source arrangement was in the best interest of the government. The ensuing study examined four potential options for developing a second source.

The first was purchase of the rights to manufacture the engine through a design disclosure package so that an exact copy could be built by another manufacturer. This option is known as a Technical Data Package (TDP). The evaluation of this option stated that the risks were high; because of the difficulties of transferring technical knowledge (among other factors), there was no historical base for successfully developing an alternative manufacturing source for a major system or subsystem using a TDP. In the cruise missile engine case, the costs may also have been high because of a WIC claim of limited rights on 145 component parts in the F107 engine. Although the burden of proof for limited rights would have been on the contractor, the lengthy litigation process could have adversely delayed the cruise missile program schedule and been expensive for the government as WIC was financially dependent on the success of the F107 program.

The second option was to develop another engine that would be interchangeable with the F107 in form, fit and function; it was later called the Alternate Cruise Engine (ACE). Contractors expressing interest in ACE development included Teledyne CAE (TCAE) (with a proposal based upon their F106 engine, which had earler lost to the WIC F107), Garrett Corporation (with a design using advanced materials to produce specific fuel consumption (SFC) and thrust improvements), and Detroit Diesel Allison. It was also later claimed that the ACE could incorporate modest improvements in both SFC and thrust, given that it was to be designed almost a decade after the F107. The JEPO evaluation of the proposed contractors' proposals indicated that they were highly optimistic and risky, and that: "It would make little sense to embark on a $30 million plus program (contractor estimate) to develop and qualify an engine which is designed to meet first generation cruise missile specifications (10 year old technology) at some moderate risk, based upon contractor past performance."[1] The JEPO preference in this option was to view it as the initiation of a second generation cruise missile engine and not to pursue it for the current program unless serious technical problems were to arise with the F107.

The third option was to manufacture the F107 engine by a second source under license from WIC. It was recognized that this plan would require an in-depth legal analysis and strategy planning on the part of the contractor, since WIC would assume responsibility for licensee performance in an environment with measureable risk. In addition, it would have to be profitable for both WIC (Leader) and the licensee (Follower) to ensure their participation. All previous government second sourcing of turbine engines using this type of option was associated with high volume production requirements and saturation of industrial facility, but that would be of less concern in the present case after the WIC plant in Ogden, Utah, reached production capacity.

The fourth option was to direct WIC to develop second sources for all critical or major subassemblies or parts. WIC did develop a plan

[1] *Development of Second Source For Cruise Missile Propulsion.* F107 Joint Program Office, Aeronautical Systems Division, September 1977.

covering approximately 153 F107 engine items, using a combination of outside procurement from dual vendors and in-house production with redundant tooling. That option would have provided dual suppliers for all key engine items except for the fuel control unit, the single most expensive F107 engine component (one that constitutes between 8 and 10 percent of the current total engine cost).

Of these four second source options evaluated by the JEPO in its September 1977 study, the fourth was clearly identified as having the lowest cost and risk. The first option was not recommended, the second was viewed as a long lead, high cost alternative, and the third, although attractive, was viewed as being only as strong as the strength of the primary contractor (WIC). At that time WIC did not want to participate in a Leader/Follower licensing agreement. In addition, the third option also might involve the resolution of the proprietary data rights issue between the government and WIC before it could be enacted (since some forms of this alternative include a TDP); it was not seriously considered. The fourth option was selected, with option two viewed not necessarily as a second source contingency but as a method for starting a second generation cruise missile engine program.

On November 2, 1977, the JCMPO authorized the JEPO to implement the component and subassembly second sourcing option, and stated that authorization to proceed with option two would require EXCOM approval. Option three was not pursued at that time. At the EXCOM meeting on November 17, 1977, second source engine development (in this case the ACE) was recommended as a hedge against a monopoly during production and to permit an increase in production rate beyond WIC's capability. Furthermore, such a second source effort was to be viewed separately from engine improvements for a follow-on cruise missile. It was not to be viewed as a competition for the WIC engine but as a backup in the event of problems. Authorization was given to proceed with the second option--the development of the ACE--which would be essentially interchangable with the F107, while exhibiting modest performance improvements over it. The EXCOM also directed that an alternative source be developed for cruise missile engines to hedge against potential technical/operational problems with the F107 and inordinate

Although there was never any criticism of the performance of WIC before or during the period that second sourcing was being considered, the cancellation of the B-1 program and the subsequent increased emphasis on the ALCM generated a new and dynamic development environment. Given that WIC was a small privately owned company at that time, it was certainly within the government's best interest to reduce potential production risk by utilizing some form of second sourcing arrangement. WIC had not yet demonstrated a capability to produce engines of this complexity in the quantities that would be needed. For example, before the second sourcing process, approximately three months were needed to manufacture a combustor for the F107 engine. This is in sharp contrast to the need for approximately *10 per day* at potential rate levels. Initially, the use of second sources for all critical or major subcontracted subassemblies or parts was viewed to be acceptable in reducing this production risk. After initiating this risk reduction option, the JCMPO remained interested in developing a second source for the *entire F107 engine*, both to further ensure production capacity and as a means of reducing costs by using split-buy competitions during the production phase.

On January 13, 1978, General Lew Allen, Commander, Air Force Systems Command, requested that the JCMPO conduct another study to determine whether the costs of developing a second engine source, in this case the ACE, could be overcome by the advantages of a price competition for some split of production. The resulting analysis, completed in March 1978, indicated that the production of the F107 by WIC (Leader) and a second manufacturer (Follower) to be selected was the most cost effective. It showed that this alternative could be between \$64 and \$94 million[2] dollars (FY78) less expensive for RDT&E costs alone than pursuing the ACE and generally would have lower associated risk. Negotiation of any resulting licensing agreement, however, might still necessitate resolving the data rights issue if directed licensing or competitive procurement forms of this option were to be used.

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[2] The estimate was later increased to between \$66.9 to \$109.7 million (FY 78).

Meanwhile, to ensure availability of an alternative approach, the JCMPO continued to persue development of the ACE. On February 10, 1978, it published a sources sought notice in Commerce Business Daily for ACE development. The intention was to release a request for proposal (RFP) for the ACE on March 31, 1978. At the March 10, 1978 EXCOM meeting, a list of contractors expressing interest in the sources sought notice was discussed, and it was stated that in the opinion of counsel, WIC could be excluded from ACE development as long as it was independently funded to develop an improved cruise missile engine. Initially, WIC management did not believe that the JCMPO really intended to develop the ACE, particularly since the previously mentioned option four was being implemented. The JCMPO, however, was serious about pursuing the ACE option and forced a change in WIC strategy. In WIC's case, it would not be in its best interest to have another engine contractor, and future competitor, receive up to $110 million (FY78) for RDT&E costs for the ACE. Viewing it as the lesser of two evils, on March 30, 1978, WIC proposed to the JCMPO a Leader/Follower option involving both WIC and a second contractor to produce the F107 engine. The JCMPO's main concern at that time was whether there could be true competition between WIC and the Follower, given that WIC would have technological learning and hidden knowledge advantages at least in the early split-buys.

Several points were contained in the Basic Agreement and Task Change Proposal that WIC submitted to the government on March 30, 1978. First, legal ownership of the disputed data rights would be determined in the future and, in the interim period, the government would have use of limited data rights with certain conditions. Second, WIC would conduct a competition and select, with government approval, a licensee to serve as the Follower for building the F107. Third, before producing a fully qualified engine, the Follower would serve as a subcontractor to WIC. Fourth, the royalty percentage to be paid to WIC by the licensee was specified. The fee would be paid only if a separate contract was issued to the Follower (breakout). Fifth, the government would have the right to require the Follower to disclose and grant rights to the government pertaining to all proposals, cost history, projected cost, and other information so long as they were subcontractors. Finally,

split-buy percentages for direct competition between WIC and the Follower were given beyond a minimum guaranteed quantity for WIC. If WIC did not perform satisfactorily, the government could procure all engines from the licensee whereupon WIC would only receive the royalty payment.

At the April 4, 1978 EXCOM meeting both the WIC Leader/Follower licensing proposal and ACE were discussed. There was little difference viewed between the two alternatives regarding risk associated with management, labor, and financial elements, or with loss of facilities, but the WIC licensing alternative tended to protect against production risk, and development of the ACE tended the protect against design risk. The F107 Leader/Follower option offered one design with two contractors, while producing the ACE would entail having two different designs and producers. There was no reason, based upon testing performed to date, to suspect the F107 design, so the WIC licensing alternative did not appear very risky. It was also viewed as being more attractive from a schedule standpoint, as it was estimated to achieve production capability in mid-to-late 1982 versus January 1984, for the ACE Because of these factors, and the cost balance in favor of a F107 Leader/Follower alternative, the JCMPO was directed to proceed with but the WIC licensing program; and the ACE competition was deferred indefinitely, although an examination of a follow-on engine (WIC 14A6) was to be made.

Even before agreement with the JCMPO on all the terms of the licensing agreement, WIC conducted a competitive licensee selection process with government participation in site surveys of the offerors. Meanwhile, at the May 12, 1978 EXCOM meeting, recommendations for two improved cruise missile engine options were presented. The first was remarkably similar to performance specification improvements sought for the ACE. It was also generally compatible with the F107 in form, fit, and function, although minor airframe modifications might be required. Although that alternative could be a derivative of the WIC F107, a second candidate option was recommended that would potentially offer more performance improvements.

During the period from the May 12, 1978 EXCOM meeting to August 30, 1978, when the licensing agreement was signed between WIC and the JCMPO, the proposal continued in a negotiation phase between the two parties. At the June 14 EXCOM meeting, serious consideration was again given to using the ACE option versus continuing with the Leader/Follower approach. At least a portion of the friction between the government and WIC centered around the choice of the Follower for the F107 engine. Six companies were initially evaluated by WIC--Garrett, TCAE, Detroit Diesel Allison, Pratt & Whitney, Sunstrand, and Solar.

WIC's initial choice was a company that at the time had no experience in the manufacture of an engine similar to the F107. The presumed strategy was to choose a Follower that would not pose a threat to it in the current or future programs. The JCMPO, however, was interested (among other things) in a Follower with a high rate manufacturing capability, because production risk associated with meeting the ALCM schedule was the initial reason for second sourcing the F107 engine. After the site surveys, three potential Followers were designated to be acceptable.

When several additional factors were later considered, TCAE was recommended by the JCMPO as a counter-proposal to WIC's choice; it was later agreed to by WIC as the F107 engine Follower. The first factor was that TCAE had successfully manufactured the Harpoon (J402) engine at rate capacity. Although the J402 and the F107 engines are different from a design viewpoint, the manufacturing processes involved for both are similar. Second, WIC (Walled Lake, Michigan) and TCAE (Toledo, Ohio) are close to each other--a desirable condition to minimize delays in the technology transfer process between Leader and Follower. Finally, TCAE had a greater familiarity with turbofan engines suitable for cruise missiles than any other potential Follower, having taken their F106 engine into advanced development as part of the SLCM airframe competition. As an outcome of discussions between WIC and the JCMPO, TCAE was named as the Follower on September 18, 1978.

The licensing agreement signed between WIC and the JCMPO on August 30, 1978 incorporated many of the points given in the March 30, 1978 Basic Agreement and Task Change Proposal offered by WIC. A summary of

the production sharing and royalty structure agreed upon is given in Table E.1. Although the government retains the option to breakout TCAE, since it is currently a fully qualified supplier, at the time of this writing they have not exercised that option and TCAE remains a subcontractor to WIC.

The technology transfer process was approximately twice as costly ($36 million vs. $18 to $19 million) as originally planned. That, however, was still only one half to one third of the estimated "front end" cost had the ACE been developed. In addition, performing the technology transfer process with TCAE is believed by JCMPO officials to have made WIC a more efficient competitor, since it forced WIC to more fully understand the rate production process.[3]

Table E.1

PRODUCTION SHARING AND ROYALTY STRUCTURE ON THE F107 ENGINE

Production Subcontracted Through WIC

Monthly Rate	WIC Minimum	TCAE Maximum
20	20	0
21 to 100	20 + 25% over 20	75% over 20
101+	20 + 25% over 20 + 50% over 100	75% over 20 + 50% over 100

Royalty Structure
(To be paid only if breakout occurs)

1 to 500 engines:	5% of the sales price
501 to 1000 engines:	4% of the sales price
1001 to 6000 engines:	3% of the sales price

Royalty payments no longer apply after 15 years or delivery of 6000 engines from either source

A delay occurred early in the technology transfer process because WIC failed to release the complete F107 data package to TCAE. That was caught by the government at the first quarterly Production Readiness Review and corrected. Although the delay was accommodated with no adverse schedule effect, problems of that type necessitate close government scrutiny to prevent their occurrence during the technology transfer process.[4] Despite that initial problem, the F107 engine program at WIC and TCAE is currently on schedule. In October 1981 TCAE successfully qualified its first F107 engine,[5] and is expected to generate its first production engine in December 1982.

Although proceeding with the ACE would have given an increased capacity for producing cruise missile engines, it would not have been cost competitive with the WIC F107 engine unless a technological breakthrough had occurred. It would have been difficult to justify the ACE strictly on cost effectiveness grounds, but the modest performance improvement it was planned to offer would provide a hedge against potential cruise missile performance degradations (e.g., because of increased weight).

It is estimated that WIC would have built approximately 2,000 F107 engines before the first ACE could have been produced. The learning curve advantage that WIC would have had in that case would probably have been insurmountable. Consequently, factors other than cost (e.g., performance improvements) would have to have been utilized by the government for the ACE producer to have been able to win any production split beyond the guaranteed percentage.

In the current Leader/Follower arrangement, it is possible that learning curve factors (although less important in the present identical design Leader/Follower case than with the alternate design ACE) and the benefit of hidden (production) knowledge may provide WIC with an advantage in competing for the non-guaranteed portions of the split buy.

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[3] The JCMPO contends that WIC price reductions achieved during the negotiated FY81 buy (discussed later in this appendix) are in large part a result of this increased WIC production efficiency.

[4] A more extensive discussion of the Leader/Follower technology transfer process is given in Appendix F.

[5] The F107 engine qualification was reconfirmed in December 1981 to ensure compliance with Mil Standard 1567.

Even before completion of the first production split buy, the JCMPO has apparently achieved some production cost avoidance from WIC. The FY80 unit engine price (sole source) was \$172 thousand[6] for 228 engines, which grew to a *bid* price of \$209 thousand for 531 engines in FY81. WIC, now faced with competition, is apparently taking steps to retain its market position. The resulting FY81 *settled* price was \$156 thousand, or a reduction of \$53 thousand per engine for the 531 engine buy. Although the first competed production buy (FY82) between the two contractors is yet to be concluded ... this writing, procurement savings of up to \$240 million versus a sole source approach are currently projected by the JCMPO for the first generation cruise missile applications.

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[6] All cost values quoted in this paragraph are in then-year dollars.

Appendix F
PRODUCTION

The basic direction used by the JCMPO Production Division is given in DoD Directive 5000.34, "Defense Production Management" (dated October 31, 1977), which "establishes policy and assigns responsibilities for production management in the Department of Defense during the acquisition of defense systems and equipment." Furthermore, it specifies that each DoD Component having responsibility for the acquisition of major systems shall establish a focal point for the production management function.

In the JCMPO, that focal point was the Production Division. The project director gave the Production Division a wide latitude in terms of interacting with contractors, identifying potential problems, and solving these problems. This proved to be a fortunate approach because the tight production schedules for the required subsystems could not be noticeably slipped without affecting ALCM (and to a lesser extent SLCM) deployment schedules.

The Production Division within the JCMPO is split into two groups, designated as Production Planning and Production Operation Branches. The Division Director (currently an Air Force Major with a background in SRAM production) is responsible for evaluating, organizing, directing, and controlling all activities relating to production management, scheduling, and use of Government Furnished Property (GFP). The Division Director directs and administers the JCMPO production program through: Production Master Scheduling, Production Readiness Reviews, Planning for Rate Reviews, Site Surveys, production plans, priorities and allocations of critical materials, Production Capability Reviews, and other methods.

The Production Planning Branch is responsible for evaluating, organizing, directing, and controlling activities relating to production planning, scheduling, and use of GFP. The branch insures the effectiveness, integrity, and compatibility of the JCMPO production management program, translates programmatic guidance into comprehensive and integrated production plans for the Air Force, Navy, and OSD, and

assures that responses to higher authority involving production schedule changes are fully integrated among users, contractors, JCMPO programs, and Service and DoD budgets. It develops the JCMPO requirements to meet Air Force and Navy operational capabilities and translates those requirements into production schedules and GFP requirements for each contractor. It develops and maintains the JCMPO task structure, which defines cruise missiles objectives and all major program elements in sufficient detail to permit development of the JCMPO program and project plans and schedules. It develops, issues, and maintains the master Requirements Analysis Document (RAD), which displays the total of user Command requirements, plus associated ship overhaul schedules, base activation plans, wing and fleet deployment plans, and other support and program ground rules. The RAD is the principal planning document and the primary JCMPO Budget Support Document for production activities.

The Production Operations Branch maintains information on the manufacturing status of all cruise missile systems, conducts planning and organization tasks required for manufacturing reviews within the JCMPO, and ensures that the contractor's corrective actions are implemented on production and production engineering problems that affect the delivery of cruise missiles and subsystems. Major areas of responsibility include: the planning, organizing, and coordinating of the various reviews used; serving as the Division focal point for providing production inputs to contractual documents; and monitoring contractor performance on manufacturing planning tasks other than hardware requirements and hardware surveillance.

Among the reviews used by this Branch, the production readiness review (PRR) is one of the most important and is used to minimize production uncertainty and to ensure that the contractor is capable of meeting rate production goals of a given system or subsystem. The objective of a PRR is to "verify that the production design, planning, and associated preparations for a system have progressed to the point where a production commitment can be made without incurring unacceptable risks of breaching thresholds of schedule, performance, cost, or other established criteria."[1] DoD policy requires a PRR before the beginning of production.

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[1] DoD Instruction 5000.38, "Production Readiness Reviews," January 24, 1979.

Key areas evaluated in the PRRs conducted by the JCMPO include: production engineering, manufacturing management systems, quality assurance, subcontracts, logistics, and software. While the Production Operations Branch is responsible for conducting PRRs at the prime and associate contractor level, the associate contractors are themselves responsible for conducting PRRs with their major subcontractors (i.e., MDAC with Litton before the INE breakout) to ensure the capability of those suppliers.

SECOND SOURCING TECHNOLOGY TRANSFER

One of the important tasks of the Production Division is to ensure the successful establishment of the dual-source Leader/Follower production arrangements that have been used by the JCMPO.[2] As performed by the JCMPO Production Division, the process of transferring technology from the Leader to the Follower is divided into four sequential parts. The first involves participating in the development and implementation of effective incentives. These may include capital investment incentive clauses, technology transfer cost payback arrangements, and additional quantity splits of the various procurements.

The second involves the Follower (or second source) assembling subsystems in kit form or disassembling and reassembling a complete subsystem provided by the Leader, and getting online the tooling and test equipment that will be used during production. The Follower typically assembles several subsystems to substantiate that it can assemble and test them. In the guidance system case, Litton Systems Limited (LSL) (the Follower) built a number of INEs from kits supplied by the Guidance and Control Systems Division of Litton Industries (LG&CS) (the Leader). In the AUR airframe case, MDAC (the Follower) will disassemble, then assemble, one SLCM airframe provided by the JCMPO as GFE. That will be followed by MDAC assembling four SLCMs from kits provided by GD/C (the Leader).

[2] One advantage of the Leader/Follower dual sourcing approach is that the Leader can be held contractually responsible for the production quality of the Follower.

The third step in this process involves the production of the subsystem by the Follower using parts manufactured by the Follower or supplied by the Leader. In addition, the Follower qualifies his selected vendors that will be required for subsystem production. In the guidance system case, LSL procured some parts from vendors LSL had qualified, manufactured other required INE components, and assembled and tested the subsystems. In the AUR airframe case, MDAC will manufacture, assemble, and test four airframes from hardware manufactured and supplied by GD/C.

The fourth step involves the substantiation of complete manufacturing of all parts by the second source, with a PRR evaluation conducted by the JCMPO after substantiation. The Follower then enters rate production, with the quantity determined by the terms of the second sourcing agreements and the outcome of yearly competition against the Leader.

In the guidance system case, the technology transfer process was judged to be quite successful, with a minimal amount of government involvement. That was, in large part, a result of LSL having previously manufactured and assembled INE key components for other programs, coupled with the fact that both the Leader and Follower are divisions of the same corporation.

In the F107 engine case it was considerably more difficult to complete the technology transfer process between the Leader (WIC) and Follower (TCAE) for several reasons. First, engine design was highly complex and somewhat immature (at that time), so the challenge was to transfer undocumented manufacturing processes knowledge. Second, WIC did not initially recognize the difficulty of producing key engine components at the necessary manufacturing rates. For example, during the development phase the time necessary to produce one combustor was approximately three months. It would be necessary, however, for WIC to be able to manufacture approximately 10 combustors *per day* during the production phase. To remedy this problem, WIC applied the results from a JCMPO producibility analysis, first to examine its own capabilities and practices, then to plan the expansion of its facility in preparation for rate production. That was followed by WIC performing a throughput

analysis to determine exactly how many engines it could build per day. The result was WIC's increased awareness of the manufacturing complexities involved and the technical approaches necessary to minimize production risk.

USING COMPLETELY VS. FUNCTIONALLY IDENTICAL PARTS

In the process of qualifying a second production source, it has been found important to distinguish between parts that must be produced identically, regardless of manufacturer, and those parts that permit some leeway in detail design parameters or manufacturing processes. Utilizing completely identical parts minimizes potential problems associated with interchanging parts between contractors but can greatly increase overall production cost. If the parts are functionally identical, the cost of production may be reduced, but divergent design problems may occur that in the long run can increase total system cost through increased O&S costs. Consequently, when second sourcing is used, a balance must be struck between using parts that are completely identical and those that are functionally identical in a given subsystem. To ensure the success of this approach, it was necessary to have a Joint Configuration Control Board (JCCB) within the JCMPO to determine the extent to which functional changes can be made, while monitoring the design approach used by the contractors to ensure the compatability of the resulting parts.

For a subsystem such as the engine or guidance, many identical parts are a necessity because of the close tolerances required. For an airframe, however, manufacturing parts to be functionally identical has a higher degree of application because there will be minimal on-site user maintenance and because each missile will be recertified each time it is returned for maintenance under the AUR warranty concept. Obviously, components that are functionally identical must still be approved by the JCCB. It is estimated that by following this approach for dual source production of the AUR airframe, at least $50 million may be saved.

PRODUCTION INTEGRATION

A key to the success of the cruise missile program is the production schedule integration process. Within the JCMPO, this process is planned and monitored by the Production Planning and Operations Divisions respectively.

The cruise missile deployment rate is expected to increase through the mid-to-late 1980s. This planned deployment could be jeopardized by a delay in systems integration or subsystem production. This is a concern because of the complex nature of the production integration process, which becomes more critical as the GLCM and SLCM enter their production phases during the next two years, with MRASM entering into production downstream. Compounding this potential problem is that the government has chosen to play a key role in the systems and production integration process (in part through the use of breakouts to reduce subsystem procurement costs), and hence is assuming an increasing amount of responsibility for the integration effort.[3] The effect of this government decision on the systems and production integration process remains to be seen and may warrant examination at a later date.

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[3] An example of this involves the land attack guidance system. Before FY82 the JCMPO purchased the Litton INE through MDAC, which was responsible, as part of its JCMPO contract, for conducting PRRs at Litton and thus monitoring Litton's ability to meet rate production. Beginning in FY82, however, the JCMPO contracted directly with Litton for INE purchases (breakout) but also took on the burden of conducting the necessary production reviews.

Appendix G
CRUISE MISSILE LAND-ATTACK GUIDANCE SYSTEM

After the selection of MDAC as the SLCM guidance prime contractor, the Navy Cruise Missile Project Office tasked MDAC to test and evaluate a number of candidate alternative Inertial Navigation Element (INE) designs (although not necessarily interchangeable in form, fit, and function) and technologies for use with TERCOM as a land attack cruise missile guidance set (CMGS).[1] For example, in November 1975, only one month after being selected as the guidance contractor, and with LG&CS as a major subcontractor, MDAC was directed to evaluate the Honeywell-produced Ring Laser Gyro system, an alternative technology design to the LG&CS INE. The primary motivation behind evaluating other candidate INE designs was to determine if any such system could meet cruise missile guidance performance requirements at a substantially lower cost.[2] The alternative INE designs were not, at least initially, being compared for possible competitive production phase second sourcing against the existing system, but were rather evaluated for possible use in future generation, lower cost cruise missiles.

The testing of such INE designs continued well beyond March 1978 and, at times, fluctuated between government-funded and MDAC-funded efforts. In November, 1976, MDAC was directed by the Navy to develop plans for second sourcing the INE. After the January 14, 1977, DSARC II decision memorandum encouraged subsystem second source competitive procurement, plans were formulated for carrying out this alternative design and technology INE competition. In February 1977 MDAC presented second sourcing alternatives to the Navy Cruise Missile Project Office and in September 1977 presented flight test results of the candidate INE designs, coupled with appropriate software (i.e., the TERCOM

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[1] At approximately that same time, MDAC was also awarded the SLCM anti-ship guidance contract, which contemplated a modification of its Harpoon guidance system.

[2] Although these candidate INEs would be of alternate designs and technologies, their guidance function would be the same as the Litton INE selected by MDAC.

algorithms). The Singer Company, Kearfott Division (SK) had been given a no cost contract by the newly formed JCMPO for inertial navigator development, and MDAC assisted in repackaging that equipment.[3] MDAC initially wanted to build an INE in-house based upon selected components but was directed by the JCMPO to hold an open competition to reduce cost. One reason for this was that MDAC wanted a larger financial share of the guidance system, because LG&CS had approximately 65 percent of the (land-attack) contract share at that time.

In December 1977 MDAC issued a Request For Information to potential INE component suppliers, to include the inertial guidance platform, computer (with memory), and power supply. At that time it also completed preliminary system definition and system development and production cost projections for potential alternative guidance systems. In January 1978 MDAC issued a Request For Technical Information to industry in preparation for the second sourcing competition. Following the receipt and evaluation of the information, MDAC briefed the JCMPO during January and February, 1978, regarding its proposed second source competition, and on March 17, 1978, issued three different RFPs to a number of prospective offerors. Each RFP was for a portion of the INE as defined the previous December. The JCMPO advised MDAC on April 6, 1978, of its willingness to fund the second source competition and asked to review the source selection criteria and procurement plan for the second source solicitations, as well as the proposed source selection.

On May 17, 1978, JCMPO personnel were invited to visit LG&CS. Noting that WIC was allowed to license its F107 engine design in a Leader/Follower dual sourcing arrangement, LG&CS presented an alternative approach in which it would license the present INE design to a number of companies skilled in producing similar technology. LG&CS pointed out what it thought to be the advantages of that approach over the MDAC approach, such as a reduction in Life Cycle Cost because only one design (versus two) was in the maintenance and supply chains.

While LG&CS was willing to consider licensing the INE, it was clear that it would only do so for certain items, not including the critical

[3] SK had previously been a major subcontractor to E-Systems during the competition to determine the cruise missile guidance prime contractor.

gyroscope and accelerometer components. LG&CS claimed that in the period beginning in 1960 it had invested over $50 million of discretionary R&D funding into technology leading to its inertial platform and other key components used in its current cruise missile INE. As early as the flyoff held between MDAC and E-Systems in 1975, LG&CS was unwilling to agree to provide the government with unlimited data rights pertaining to these components, claiming that they were trade secrets that would result in irreparable harm if made public. Consequently, LG&CS refused to provide unlimited data rights on 15 components it considered to be proprietary. Similarly, only limited rights in LG&CS's data flowed up to the government from MDAC, whereas the government received unlimited rights to almost all data except LG&CS's. In October 1977 and May 1978 LG&CS reiterated its propretary rights claim for the original 15 items, plus additional ones. LG&CS stressed that its data was proprietary, would be submitted with only limited rights, and could not be used in the MDAC RFP or technical descriptions for second sourcing.

During the May 17, 1978 meeting, LG&CS discussed the technology transfer process, stating that the success was determined by the ability to transfer *processes* and ***knowhow***, not products, to a Follower, and that LG&CS had done this successfully 36 times in the past. Although LC&GS was willing to discuss a licensing alternative with the licensee to be selected by the government, the implication was that because of the limited data rights issue, such a discussion could occur only with a sister division providing the key components, including the gyroscopes and accelerometers. All the examples of technology transfer given involved using LG&CS as the Leader and other Litton divisions as the Follower, so it was possible to use this option to dual source the cruise missile INE. On June 7, 1978, another meeting was held between Litton and the JCMPO. During that meeting, Litton presented seven examples of competition in the past between LG&CS and Litton Systems Limited (LSL) of Canada using technology similar to that in the cruise missile INE. Competition between Litton sister divisions had apparently been keen enough that in several instances, one Litton division had underbid another.

A memorandum of agreement (MOA) was later drafted between the JCMPO and LG&CS (the Leader) to establish LSL as the second source (Follower) for the cruise missile INE components supplied by LG&CS. The MOA outlined five major items. The first was an agreement on steps to establish a dual source capability for cruise missile guidance components with LSL, including the necessary transfer of technology from LG&CS. The second specified that LG&CS and LSL should work as independent contractors with neither division having any responsibility for cost, schedule, or performance of the other division. Litton corporate personnel were also restricted from participating in any LG&CS or LSL proposal or price reviews and from information that could affect either division's pricing strategy regarding INE production. The third precluded royalty charges or license fees to the government between Litton divisions for the resulting technology transfer.[4] The fourth limited the profits charged to the government by LG&CS and LSL. The fifth provided Litton an appropriate capital investment incentive clause for inclusion in applicable procurements pertaining to purchasing the necessary equipment to achieve producion capability.

On August 4, 1978, MDAC presented the JCMPO with its methodology, requirements, and the approach being utilized in the second source RFPs. On August 11, 1978, the JCMPO requested that MDAC include the licensing approach between LG&CS and LSL in its evaluations. At that time the JCMPO was faced with several tradeoffs between the identical design, and alternate design or technology approaches for second sourcing the cruise missile INE. Previous JCMPO analyses indicated that identical design licensing between the two Litton divisions would produce the lowest "front end" and Operations and Support (O&S) costs, and the lowest schedule risk to the ALCM program, of any of the dual sourcing alternatives examined.

The "front end" costs[5] were estimated at the time by an independent study to be approximately $40.8 to $61.3 million more, and O&S costs to

[4] Since royalty charges would be precluded, this licensing approach was equivalent to a Leader/Follower arrangement.

[5] All costs quoted in this paragraph are in FY77 dollars.

be $1.2 to $4.2 million more, for the alternative design or technology approach than for the Leader/Follower licensing approach (based upon approximately 5200 units and a 15 year life cycle). Of these additional "front end" costs, $16.8 to $21.8 million were estimated for contractor development, $2.6 to $16.6 million for initial Integrated Logistics Support (ILS), and $21.4 to $22.9 million for Tooling and Test Equipment (TATE). The latter two costs represent non-recurring investment costs. The lower development cost expected for the Leader/Follower approach was because there would be no cost to the government for the transfer of technology from LG&CS to LSL. The additional estimated ILS cost reflected government costs to establish the support force for two systems versus one (Litton and SK versus Litton INEs). The additional TATE costs represented the loss of the Litton Corporate commitment to capitalize such costs if LSL was not the second source, plus TATE costs involving SK if it were chosen the second source. Additional ground and flight qualification tests would have been required if the alternative design or technology approach was selected. Although somewhat speculative, estimates of the cost for those tests indicate that they may have been $25 to $50 million. The estimated costs for 1610 units of a mix of LG&CS and SK, versus LG&CS and LSL, INEs was estimated to be an additional $2.3 to $40.5 million (FY77) depending upon whether SK provided all (more expensive) or some (less expensive) of the INE components. This, coupled with the higher "front end" and O&S costs, indicate that the Leader/Follower licensing approach would probably been less costly than the alternative design or technology approach.

In favor of the alternative design approach was the *possibility* of achieving greater cost savings in the production phase than in the Leader/Follower licensing case, through a possibly more productive competition between LG&CS and another designated second source than between two Litton divisions.

On August 31, 1978, MDAC advised the JCMPO of its conclusions regarding the second source RFP responses and its preliminary evaluation of the Leader/Follower licensing approach. In the early part of September 1978, LSL submitted an unsolicited proposal to MDAC to produce portions of the INE under license from LG&CS. Between September 7 and

14, 1978, the JCMPO reviewed MDAC's evaluation of the technical proposals under the RFPs. On September 15, 1978, in a presentation to the JCMPO, MDAC advised that none of the second source offerors presented as low a risk at minimal cost as the Leader/Follower licensing approach, and on October 13, 1978, MDAC with the concurrence of the JCMPO decided that no awards would be made under the RFP. On that date, the MOA between the JCMPO, MDAC, and Litton Systems, Inc. was signed specifying the Leader/Follower licensing approach to be used between LG&CS and LSL in the production of cruise missile INEs.

A Technical Assistance and Licensing Agreement between LG&CS and LSL covering the transfer of technology for the cruise missile INE and associated support equipment from LG&CS (Leader) to LSL (Follower) was submitted to the U.S. State Department for approval on November 8, 1978. The agreement was approved on July 5, 1979, and will continue in effect through June 23, 1989, unless canceled by the participants.

On October 16, 1978, MDAC advised the offerors of the decision to withdraw the RFP. SK, a bidder for an alternative design INE in response to the MDAC RFP, protested its cancellation on October 20, 1978 to the General Accounting Office (GAO).

The basic thrust of SK's protest to the GAO was whether the alternative design and technology cruise missile INE competition had been properly canceled in favor of the Leader/Follower arrangement between LG&CS and LSL. SK presented several points to the GAO. First and most important, SK claimed that it had been denied the opportunity to compete with LSL on an equal basis. Second, it contended that there could be no true price competition between LG&CS and LSL because both were divisions of the same corporate entity. Third, SK contended that there were procedural flaws in the MDAC RFP and in the JCMPO's reasons for canceling the RFP in favor of the LG&CS-LSL Leader/Follower arrangement. Fourth, SK argued that no competitive range was established under the RFP, no negotiations were conducted, and there was no common cutoff date for best and final offers, all procedures that were required under the "federal norm" applicable to the procurement. Finally, SK claimed that the LSL proposal was submitted four months after the closing date for proposals, and that the sole sorce award to LSL violated provisions of the Defense Acquisition Regulations.

Each of these points was disputed by the JCMPO and Litton. The GAO considered each item, found the SK position wanting, and upheld the government's position of the case on each point and denied the protest. The GAO ruling, issued on June 6, 1979, emphasized the discretion inherent in a procurement decision made by the government program manager. It supported the JCMPO position on commonality, which presumed the program office's discretion to choose whether it thought alternative or identical design second sourcing would better fulfill the government's needs, and on selecting the option that would minimize schedule risk to the ALCM program. The latter issue was related to the increased importance of the ALCM to national security after the cancellation of the B-1 bomber program, and in reality to the change in circumstances viewed by the JCMPO that led it to withdraw the MDAC RFP.

Issues that were weighed in the cruise missile INE procurement competition included production and schedule risk and cost reduction. Production risk associated with the Leader (LG&CS) was not viewed as important as in the cruise missile engine case because LG&CS had previously built components for over 2,000 similar INEs for other programs. However, production and schedule risk with the Follower was another consideration because of the early ALCM IOC date coupled with the perceived national importance of this weapon system. Finally, unit cost reduction was perceived to be a desirable possible outcome of the competition. In the cruise missile engine case, cost considerations were overshadowed by production and schedule risks.

Perceived disadvantages of the alternative design or technology approach, in addition to cost considerations, included utilization of an unproved design, high risk in meeting rate production on schedule, and a learning curve advantage to LG&CS before any second source production competition could start. Similarly, perceived non-cost advantages of the Leader/Follower licensing approach included the use of a proved technology INE and lowest overall program risk, and the primary hardware supplier would be responsible for quality, reliability, and performance.

Although a cursory examination of the negotiations may indicate that the JCMPO attempted to save present dollars, several other issues affected the decision and warrant discussion. First, MDAC had developed

a long list of considerations to be evaluated in choosing candidate subsystems in the alternate design and technology second sourcing competition, but it was not technically qualified to perform a detailed comparison between candidate INE components. Certain important issues, such as tradeoffs between cost and performance, were noticeably absent from the evaluation and might not have been properly performed without government assistance. Second, LG&CS claimed that its INE was superior to that designed by SK, but both systems contained gyroscopes designed by the same individual (who worked at both companies at different times), and both INEs had demonstrated similar, if not equal, performance.

Third, SK claimed that it could meet schedule requirements for rate production if its alternate design INE was chosen, but its schedule appeared optimistic. The most cost attractive alternative design INE option involved components produced from different sources. Additional costs and schedule delays would probably have resulted because of potential component interface problems, redesign of at least some hardware items, the necessity to rewrite at least a portion of the guidance and navigation software, increased system integreation costs charged by MDAC, and qualification tests that would have to be performed on the system from the beginning. Again, the increased national prominence of the ALCM program at that time probably influenced the government action. Potential rate production schedule delays associated with an alternative design or technology versus the Leader/Follower licensing approach may have delayed ALCM deployment and hence jeopardized national security, and the government may have been justified in choosing the latter approach even if the former one would have delivered an INE at a lower cost. Although SK claimed that it never submitted a best and final price offer, cost analyses performed by independent personnel indicated that a considerable reduction in the SK cost versus that from the Leader/Follower licensing approach would have been necessary to counteract higher "up front" and O&S costs.

Fourth, "up front" development costs for LG&CS and LSL were minimized by using the Leader/Follower licensing approach for three reasons: the Canadian Government agreed to underwrite approximately $43 million in TATE costs for LSL; the JCMPO offered LG&CS a capital

investment incentive clause to underwrite additional TATE they required; and no royalty or licensing fee was imposed because LSL was a sister division of LC&GS.

The final issue relates to the degree of competition between LG&CS and LSL. Each Litton division may bid standard rates and not now or in the future be willing to provide many concessions to the government. That depends, in part, on the degree of autonomy that exists between the two Litton divisions and their corporate headquarters. Apparently, the corporate structure and operating principals within Litton permits true competition between divisions. Before the Leader/Follower licensing agreement was signed, LG&CS provided examples from other programs of head-to-head competition with LSL on seven occasions using technology similar to that in the cruise missile program. Also, the transfer of personnel between the two divisions is small compared with that in other aerospace industry contractors. That may tend to reduce the flow of critical pricing and process knowledge between LG&CS and LSL.

The JCMPO's position was that the government has attempted, and will continue to attempt, to receive the best possible price in the cruise missile INE dual sourcing competition, and it has the power of the Sherman Antitrust Act to prevent a price fixing conspiracy. Furthermore, where corporate divisions, such as LG&CS and LSL, publicly adopt a competitive posture in their dealings external to their corporation (as in this case with the government), expanded anti-trust liability may be incurred under the Sherman Act.

Finally, simply using a split-buy in the production phase with two separate companies provides no guarantee that true competition will occur, particularly when the experiences of the two companies are different. In the cruise missile engine dual sourcing case, there is some question as to whether there will be effective competition between Williams International Corporation (Leader) and Teledyne CAE (Follower), because of the relative strengths of the two companies. Consequently, in the guidance case, and in other cruise missile second sourcing cases, it will be necessary to monitor the progress of the split-buys over a period of time to evaluate the degree of competition (hence potential cost savings). The initial cruise missile INE buy indicates that cost savings have occurred. If these trends continue, with INEs obtained for

the AGM-86B, GLCM, and land-attack SLCM, the JCMPO estimates a cost savings of approximately $240 million (then year dollars) will result from this production dual sourcing competition.

Appendix H
WARRANTIES

As weapon systems have become more complex in recent years, problems of overall system reliability and availability have increased. Such problems demand special attention in a strategic missile because of the high premium placed on total system reliability. The operational user needs high confidence that the system will perform properly, even though it may be employed with little or no opportunity for pre-launch checkout, after having been in passive storage for some time.

Missile reliability is harder to measure than are the usual standards of system performance such as range or delivery accuracy. Traditionally, this has led developers to put less emphasis on reliability during the early phases of development, leaving it to be achieved through design refinements and system modifications as field experience is accumulated. That approach may have some merit in a system that is repeatedly operated on a regular basis, such as an aircraft, but it is much less appropriate for a missile system where each test may result in a round being expended and only limited experience can be accumulated.

Soon after the JCMPO was established, Rear Admiral Locke decided to use reliability warranties as a management procedure to force the contractors to emphasize system reliability during both the development and the procurement phases. By establishing a specific level of reliability as a goal and negotiating a price the producer would charge for assuming full responsibility for meeting that goal, system reliability was brought to a high level of management visibility for both the developer and the project office. Reliability warranties were first investigated during the early phases of the SLCM program, but were not implemented then because the program had not progressed to the production phase. The ALCM program was the first cruise missile version to reach production and thus was the first opportunity to negotiate specific warranty clauses. At the time of this writing, three warranty contracts have been negotiated for different elements of the ALCM. Each

is somewhat different, reflecting the special circumstances and needs of that element. These are briefly summarized below.

SUSTAINER ENGINE

The initial warranty on the F107 engine, signed in the spring of 1980, covered only the engines delivered to the Air Force for the ALCM. The warranty focused on a guaranteed "Level of Performance" (LOP) that would be evaluated on the basis of three kinds of tests: (1) a series of missile flight tests conducted during operational development tests; (2) ground tests on new production engines, or engines returned for routine refurbishment after three years in the field; and (3) tests on engines removed at random from missiles deployed with operational units. In each case the tests would emphasize the ability of the engine to start and complete a mission (simulated in the case of ground tests), and demonstrate a specified level of thrust and fuel consumption rate. This warranty is different from the popular Reliability Improvement Warranty (RIW) in that it focuses entirely on demonstrated performance of the system. The contractor performs no maintenance on the engines, and supplies no spares, under the warranty provisions.

The warranty covered a seven year period ending in mid-1987. The time span was divided into six periods, the first being two years long (to cover the initial inventory buildup period) and five succeeding one-year periods. In each period a minimum number of tests was scheduled, ranging from ten to twenty. Individual test results during each test period were to be weighted and combined to produce a single-value LOP for each test period. The warranty specified a target LOP value for each test period, with the value increasing each year to stimulate an increasing level of engine reliability. If the specified LOP goal is achieved in a particular test period, the contractor is to be awarded an incentive fee, ranging from $240,000 in the first period to $600,000 in the last period. The fee increases in the later test periods because the target value of LOP is higher (and presumably more challenging), because of the larger number of engines that would have undergone prolonged dormant periods, and because the accumulation of test results will provide more confident predictions of engine reliability and permit shifting more risk to the contractor.

If a failure occurs during any of the warranty demonstration tests, the contractor is obligated to provide, at no further cost to the government, a detailed analysis of the failure and, if appropriate, a proposal for correcting the source of the problem (including retrofit of earlier engines as well as changes in production of future engines). If the government approves of the proposed corrective action, the contractor must perform the work *at its own expense* (subject to limitations discussed below).

In addition to the incentive fee that can be earned by the contractor for successfully meeting the target LOP values, a warranty "allowance" of $5 million was granted to the contractor to cover the anticipated corrective actions. Furthermore, a ceiling of $8 million was placed on the cost of corrective actions for which the contractor could be held liable. Thus, if all LOP goals were achieved and no corrective actions were necessary throughout the seven year life of the warranty, the contractor could gain a maximum of $8 million, while his maximum loss is limited to $3 million.

In 1981 the warranty was modified slightly to cover all engines produced for the cruise missiles, including SLCM and GLCM as well as ALCM.

ALCM INERTIAL NAVIGATION ELEMENT

Concurrent with negotiations for the engine warranty, an attempt was made to devise a warranty to cover the ALCM guidance system. In principle, the guidance system is somewhat easier to warranty than an engine because the guidance components can be periodically tested in the field and any failed units can be readily replaced in the missile. However, negotiations were complicated by the fact that McDonnell Douglas Astronautics Company (MDAC) was the prime contractor for the overall guidance system, but much of the hardware for that system was subcontracted. Failing to negotiate a mutually satisfactory warranty liability and incentive clause with MDAC, the JCMPO settled for a warranty on the inertial navigation element (INE) alone. That warranty, signed with the Guidance and Control Systems Division of Litton Industries and covering a period of five years, contains two separate

provisions. The first is a conventional RIW. During the warranty period the contractor is obligated to repair or replace any failed unit and to maintain a sufficient stock of spares that the resupply cycle time does not exceed a specified value. The contractor has the option of submitting no-cost engineering change proposals to correct any troublesome design features, and if approved the design change must be incorporated into all future production units and all units returned to the contractor for service. The RIW clause also contains a guaranteed mean time between failure (MTBF) for each one year period of the warranty, with the MTBF goal steadily during the life of the warranty. Failure to meet the MTBF goal for any one-year measurement period means that the contractor has to perform additional failure analysis and take corrective design action, again at no further cost to the government.

In addition to the RIW provision, the warranty also includes an availability guarantee. Under this clause the contractor guarantees that a specified percentage of the units will pass ground checkouts, thus contributing to an assurance of operational availability of the overall missile system. A test program is specified in the warranty, and tests conducted throughout each one-year period are accumulated to determine the overall rate of INE availability. If the INE fails to achieve the specified availability rate, the contractor is obligated, at its own expense, to conduct a failure analysis and to submit design changes necessary to correct the deficiency. If approved by JCMPO, the contractor is then obligated to incorporate those design changes in all warranted units. A single warranty fee of approximately $2.35 million covered non-recurring activities, and an additional annual fee was negotiated to cover design modifications and retrofits. That annual fee was something over $10 million for each of the first two years but is expected to be somewhat less in future years as the design aproaches maturity.

ALCM AIRFRAME

The remaining warranty contract clause that has been signed to date covers the airframe and other parts of the missile provided by the prime system contractor, but excluding GFE items such as the engine and guidance subsystems. This warranty was one of the provisions specified

in the RFP for the ALCM competition held in 1979 and became part of the contract signed with Boeing when it won that competition in 1980. Like the engine warranty, this is limited to an availability guarantee. A schedule of both flight tests and ground checkout tests is defined. The warranty target is that 94 percent of all ground tests and 90 percent of all flight tests in any one-year period shall be successful. A penalty clause and an incentive clause are provided to encourage compliance. The penalty clause is functionally similar to that of the engine warranty; any verified failure detected during a test must be analyzed by the contractor and an appropriate design change proposed. If approved by JCMPO, the design change must be incorporated into all missiles covered under the warranty, all at no cost to the government. If the design change occurs after the government has established its own depot maintenance facility, the contractor is obligated to provide retrofit kit

The incentive clause provides for a total of $2 million in fees to be paid to the contractor under a three-step schedule. One half of the fee is to be paid when the specified availability level is achieved for two successive years, an additional one-fourth to be paid upon three successive years of successful tests, and the final one fourth to be paid upon four successive years of achieving the specified availability level. The warranty, including the penalty provisions, is to be terminated when the entire incentive fee is earned or at the end of eight years, which ever occurs first. Thus, the contractor could earn a maximum of $2 million over a period of four years, or could be exposed to an unlimited liability to correct design deficiencies for a period up to eight years.

SPECIAL WARRANTY CONSIDERATIONS

A major factor that has complicated the completion of the warranty agreements is that a warranty interacts with so many aspects of both the acquisition process and the operational support policies of the user. One difficulty was that some officials disagree with the basic warranty concept, arguing that the supplier is being paid extra for delivering something that was already specified in the contract. A more serious problem was that the Air Force prefers to perform system maintenance and

repair largely through "organic" resources rather than rely on commercial concerns (such as the supplier of the item). The Air Force did agree to a RIW contract for the ALCM INE, with the supplier performing all maintenance and repair during the warranty period (the first five years of production). The warranties on the engine and the airframe are limited to guarantees of system availability rate, with the Air Force providing maintenance through normal field organizations. However, both of those systems remain largely dormant during their operational life, so there is really very little interaction between the organic maintenance activities and the supplier's availability guarantee.

Finally, the warranty clauses were complicated by the fact that both the engine and the INE were produced by dual sources. Since both warranties require that the supplier agree to provide a technical analysis of any failure and to provide a recommended redesign to correct the deficiency, the warrantor must have the technical capability to revise the basic component design. In general, a Follower in a Leader/Follower dual source arrangement will not possess such a redesign capability, so only the original designer of the element is technically competent to enter into a warranty agreement. Thus, the Leader must warrant not only its own products but also the products of the Follower. This was fairly easy in the INE warranty because both producers are divisions of the same corporation. In the engine warranty, WIC (the developer of the engine and the Leader) is responsible for all warranty coverage of both their own engines and those produced by the Follower, TCAE, during the period FY80 through FY84. During that time TCAE was developing a production capability, producing an initial demonstration batch of engines, and working as a subcontractor to WIC. It was therefore reasonable for WIC to be responsible for the quality of all engines produced and to perform corrective design actions as necessary. If the contractual arrangement with TCAE is changed sometime in the future, a new warranty would have to be negotiated.

Appendix I
PROGRAM COSTS

This appendix presents summary information developed from the cruise missile Selected Acquisition Reports (SAR) and budget working papers to indicate how the JCMPO and ALCM program offices have sought to contain cost growth in their programs. We will show the changes that have been recorded in the SAR cost projections for the cruise missile programs through March 1982, together with a brief discussion of the primary reasons that were given for the changes.

Costs will be identified for each of the three major missile programs (ALCM, SLCM, and GLCM) and will be further separated into Development, Military Construction, and Procurement categories. Procurement costs are further separated into air vehicle and launch and peculiar support equipment costs. A cost growth analysis was also planned for each of the major missile subsystems in terms of the requirements of the ALCM, GLCM, and SLCM programs taken as a whole. Such data would permit the identification of major subsystems that caused changes in the cost of the individual cruise missile air vehicles. Unfortunately, the required subsystem cost breakdowns were unavailable for the ALCM missile; consequently that analysis could not be completed.

Summary data are also presented on the costs incurred by the Defense Mapping Agency in support of the Joint Cruise Missiles Project. That cost is not reported as a part of the cruise missile program in the SARs or other routine budget documents.

COST VARIANCE ANALYSIS

The variance section of the SAR document provides a systematic distribution of an acquisition program's cost growth among the selected categories, as reported by the program office. Table I.1 presents the baseline Development Estimate (DE) and the March, 1982, cost growth projection for the total ALCM program from the SAR in base-year (FY 77) dollars and in then-year dollars, the latter capturing the effect of

Table I.1

ALCM
PROGRAM ACQUISITION COST
(Costs in $ millions)

	Base-Yr(FY77) $		FY82 $		Current Yr $	
	Cost	% of DE	Cost	% of DE	Cost	% of DE
DEVELOPMENT (Quantities: DE= 35, CE= 24)						
DEV ESTIMATE	696.1	100.0	1077.6	100.0	751.6	100.0
VARIANCE:						
Quantity	-6.4	-.9	-9.9	-.9	-7.5	-1.0
Schedule	83.3	12.0	128.9	12.0	109.2	14.5
Engineering	156.2	22.4	241.8	22.4	204.0	27.1
Estimating	8.6	1.2	13.3	1.2	45.3	6.0
Other	-.2	.0	-.3	.0	-.2	.0
Support	44.4	6.4	68.7	6.4	81.5	10.8
(Pgm changes)	(285.9)	(41.1)	(442.6)	(41.1)	(432.3)	(57.5)
Economic					33.6	4.5
TOT VARIANCE	285.9	41.1	442.6	41.1	465.9	62.0
CUR ESTIMATE	982.0	141.1	1520.1	141.1	1217.5	162.0
PROCUREMENT (Quantities: DE= 3424, CE= 4348)						
DEV ESTIMATE	2311.6	100.0	3612.4	100.0	3281.8	100.0
VARIANCE:						
Quantity	543.5	23.5	849.3	23.5	1388.8	42.3
Schedule	-57.1	-2.5	-89.2	-2.5	85.9	2.6
Engineering	9.5	.4	14.8	.4	16.0	.5
Estimating	237.5	10.3	371.1	10.3	586.9	17.9
Other	.0	.0	.0	.0	.0	.0
Support	214.8	9.3	335.7	9.3	424.9	12.9
(Pgm changes)	(948.2)	(41.0)	(1481.8)	(41.0)	(2502.5)	(76.3)
Economic					950.4	29.0
TOT VARIANCE	948.2	41.0	1481.8	41.0	3452.9	105.2
CUR ESTIMATE	3259.8	141.0	5094.1	141.0	6734.7	205.2

Table I.1
Continued

	Base-Yr(FY77) $		FY82 $		Current Yr $	
	Cost	% of DE	Cost	% of DE	Cost	% of DE
MIL CONST						
DEV ESTIMATE	121.4	100.0	191.7	100.0	150.6	100.0
VARIANCE:						
Quantity	.0	.0	.0	.0	.0	.0
Schedule	37.3	30.7	58.9	30.7	100.5	66.7
Engineering	5.9	4.9	9.3	4.9	10.4	6.9
Estimating	-7.0	-5.8	-11.1	-5.8	-10.9	-7.2
Other	.0	.0	.0	.0	.0	.0
Support	36.5	30.1	57.6	30.1	61.7	41.0
(Pgm changes)	(72.7)	(59.9)	(114.8)	(59.9)	(161.7)	(107.4)
Economic					49.7	33.0
TOT VARIANCE	72.7	59.9	114.8	59.9	211.4	140.4
CUR ESTIMATE	194.1	159.9	306.6	159.9	362.0	240.4
TOT PROGRAM (Quantities: DE= 3459, CE= 4372)						
DEV ESTIMATE	3129.1	100.0	4881.7	100.0	4184.0	100.0
VARIANCE:						
Quantity	537.1	17.2	839.4	17.2	1381.3	33.0
Schedule	63.5	2.0	98.6	2.0	295.6	7.1
Engineering	171.6	5.5	266.0	5.4	230.4	5.5
Estimating	239.1	7.6	373.4	7.6	621.3	14.8
Other	-.2	.0	-.3	.0	-.2	.0
Support	295.7	9.5	462.1	9.5	568.1	13.6
(Pgm changes)	(1306.8)	(41.8)	(2039.2)	(41.8)	(3096.5)	(74.0)
Economic					1033.7	24.7
TOT VARIANCE	1306.8	41.8	2039.2	41.8	4130.2	98.7
CUR ESTIMATE	4435.9	141.8	6920.8	141.8	8314.2	198.7

SOURCE: March 1982 SAR.

inflation. The figures shown in the center column express the costs in FY 82 currency values.

Separate tabulations are given in the table for development, procurement, military construction, and total program costs. The sum of the DE and Total Variance equals the Current Estimate (CE). The contribution of each variance category to the growth is shown in percentage terms as well. All of the SAR variance cost categories, with the exception of Support and Economic, relate to changes in the cost of the major equipment. For the ALCM program, this is mainly limited to the missile, whereas for the other cruise missiles it includes the launch equipment as well. The figure shown in the SARs for Support is the sum of all of the cost changes, regardless of cause, in the baseline estimates for the other ground support equipment, initial spares, and other peculiar support. The Economic category accounts for escalation in excess of the programmed amount and appears only in the Then-Year dollar column.[1] Tables I.2 and I.3 show similar information on the total SLCM and GLCM programs.

Although these variance distributions are not without their shortcomings, they are helpful in identifying some major problem areas. Discussions with JCMPO personnel augmented the material presented in the SARs to explain the primary reasons for cost growth in the individual cruise missile programs.

Because the SAR categories are not mutually exclusive, there is considerable freedom in the choice of where to record a given cost change, and the procedure is inconsistent between programs and even from one quarter to the next. The explanation for a current change is often

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[1] The JCMPO staff contends that the real cost growth of the cruise missile programs are overstated to some extent as a result of the inadequate correction allowed for inflation. The official inflation indexes supplied by the Office of Management and Budget have been low. As a result, a portion of the inflation-induced cost growth that should properly have been recorded as Economic variance was allocated instead among the other variance categories, principally Estimating. That view is supported by a Congressional Budget Office special study entitled *A Review of the Department of Defense December 1981 Selected Acquisition Report* (May 1982). That study, discussing DoD changes applied to inflators for major weapon systems, states "By forecasting that these inflators will increase at higher rates than the overall GNP deflator, DoD has enhanced the realism of its budget predictions."

Table I.2

SLCM
PROGRAM ACQUISITION COST
(Costs in $ millions)

	Base-Yr(FY77) $		FY82 $		Current Yr $	
	Cost	% of DE	Cost	% of DE	Cost	% of DE
DEVELOPMENT (Quantities: DE= 81, CE= 74)						
DEV ESTIMATE	782.8	100.0	1211.8	100.0	866.1	100.0
VARIANCE:						
Quantity	-17.5	-2.2	-27.1	-2.2	-22.6	-2.6
Schedule	145.1	18.5	224.6	18.5	207.1	23.9
Engineering	172.6	22.0	267.2	22.0	318.4	36.8
Estimating	5.3	.7	8.2	.7	24.0	2.8
Other	.0	.0	.0	.0	.0	.0
Support	2.1	.3	3.3	.3	2.9	.3
(Pgm changes)	(307.6)	(39.3)	(476.2)	(39.3)	(529.8)	(61.2)
Economic					33.9	3.9
TOT VARIANCE	307.6	39.3	476.2	39.3	563.7	65.1
CUR ESTIMATE	1090.4	139.3	1688.0	139.3	1429.8	165.1
PROCUREMENT (Quantities: DE= 1082, CE= 3994)						
DEV ESTIMATE	1023.6	100.0	1599.6	100.0	1556.8	100.0
VARIANCE:						
Quantity	2641.0	258.0	4127.1	258.0	7649.2	491.3
Schedule	5.4	.5	8.4	.5	4.6	.3
Engineering	62.6	6.1	97.8	6.1	98.4	6.3
Estimating	-11.7	-1.1	-18.3	-1.1	-109.6	-7.0
Other	.0	.0	.0	.0	.0	.0
Support	407.5	39.8	636.8	39.8	1051.5	67.5
(Pgm changes)	(3104.8)	(303.3)	(4851.9)	(303.3)	(8694.1)	(558.5)
Economic					97.6	6.3
TOT VARIANCE	3104.8	303.3	4851.9	303.3	8791.7	564.7
CUR ESTIMATE	4128.4	403.3	6451.5	403.3	10348.5	664.7

Table I.2
Continued

	Base-Yr(FY77) $		FY82 $		Current Yr $	
	Cost	% of DE	Cost	% of DE	Cost	% of DE
MIL CONST						
DEV ESTIMATE	.0	.0	.0	.0	.0	.0
VARIANCE:						
Quantity	.0	.0	.0	.0	.0	.0
Schedule	.0	.0	.0	.0	.0	.0
Engineering	.0	.0	.0	.0	.0	.0
Estimating	-.1	.0	-.2	.0	-.1	.0
Other	.0	.0	.0	.0	.0	.0
Support	.4	.0	.6	.0	.5	.0
(Pgm changes)	(.3)	(.0)	(.5)	(.0)	(.4)	(.0)
Economic					.1	.0
TOT VARIANCE	.3	.0	.5	.0	.5	.0
CUR ESTIMATE	.3	.0	.5	.0	.5	.0
TOT PROGRAM (Quantities: DE= 1163, CE= 4068)						
DEV ESTIMATE	1806.4	100.0	2811.4	100.0	2422.9	100.0
VARIANCE:						
Quantity	2623.5	145.2	4100.0	145.8	7626.6	314.8
Schedule	150.5	8.3	233.1	8.3	211.7	8.7
Engineering	235.2	13.0	365.0	13.0	416.8	17.2
Estimating	-6.5	-.4	-10.2	-.4	-85.7	-3.5
Other	.0	.0	.0	.0	.0	.0
Support	410.0	22.7	640.7	22.8	1054.9	43.5
(Pgm changes)	(3412.7)	(188.9)	(5328.6)	(189.5)	(9224.3)	(380.7)
Econcmic					131.6	5.4
TOT VARIANCE	3412.7	188.9	5328.6	189.5	9355.9	386.1
CUR ESTIMATE	5219.1	288.9	8139.9	289.5	11778.8	486.1

SOURCE: March 1982 SAR.

Table I.3

GLCM
PROGRAM ACQUISITION COST
(Costs in $ millions)

	Base-Yr(FY77) $		FY82 $		Current Yr $	
	Cost	% of DE	Cost	% of DE	Cost	% of DE
DEVELOPMENT (Quantities: DE= 6, CE= 5)						
DEV ESTIMATE	74.8	100.0	115.8	100.0	88.7	100.0
VARIANCE:						
Quantity	-9.4	-12.6	-14.6	-12.6	-13.9	-15.7
Schedule	18.0	24.1	27.9	24.1	29.1	32.8
Engineering	3.5	4.7	5.4	4.7	4.6	5.2
Estimating	150.6	201.3	233.1	201.3	221.9	250.2
Other	.0	.0	.0	.0	.0	.0
Support	10.4	13.9	16.1	13.9	12.3	13.9
(Pgm changes)	(173.1)	(231.4)	(268.0)	(231.4)	(254.0)	(286.4)
Economic					21.8	24.6
TOT VARIANCE	173.1	231.4	268.0	231.4	275.8	310.9
CUR ESTIMATE	247.9	331.4	383.8	331.4	364.5	410.9
PROCUREMENT (Quantities: DE= 696, CE= 560)						
DEV ESTIMATE	927.6	100.0	1449.6	100.0	1365.4	100.0
VARIANCE:						
Quantity	-124.7	-13.4	-194.9	-13.4	-212.2	-15.5
Schedule	-7.4	-.8	-11.6	-.8	69.2	5.1
Engineering	32.0	3.4	50.0	3.4	56.7	4.2
Estimating	252.7	27.2	394.9	27.2	464.2	34.0
Other	90.8	9.8	141.9	9.8	160.8	11.8
Support	145.3	15.7	227.1	15.7	300.1	22.0
(Pgm changes)	(388.7)	(41.9)	(607.4)	(41.9)	(838.8)	(61.4)
Economic					439.7	32.2
TOT VARIANCE	388.7	41.9	607.4	41.9	1278.5	93.6
CUR ESTIMATE	1316.3	141.9	2057.0	141.9	2643.9	193.6

Table I.3
Continued

	Base-Yr(FY77) $		FY82 $		Current Yr $	
	Cost	% of DE	Cost	% of DE	Cost	% of DE
MIL CONST						
DEV ESTIMATE	51.2	100.0	80.9	100.0	73.1	100.0
VARIANCE:						
Quantity	.0	.0	.0	.0	.0	.0
Schedule	.0	.0	.0	.0	6.6	9.0
Engineering	.0	.0	.0	.0	.0	.0
Estimating	63.3	123.6	100.0	123.6	128.1	175.2
Other	-16.9	-33.0	-26.7	-33.0	-28.0	-38.3
Support	118.2	230.9	186.7	230.9	234.0	320.1
(Pgm changes)	(164.6)	(321.5)	(260.0)	(321.5)	(340.7)	(466.1)
Economic					-7.0	-9.6
TOT VARIANCE	164.6	321.5	260.0	321.5	333.7	456.5
CUR ESTIMATE	215.8	421.5	340.8	421.5	406.8	556.5
TOT PROGRAM (Quantities: DE= 702, CE= 565)						
DEV ESTIMATE	1053.6	100.0	1646.2	100.0	1527.2	100.0
VARIANCE:						
Quantity	-134.1	-12.7	-209.4	-12.7	-226.1	-14.8
Schedule	10.6	1.0	16.3	1.0	104.9	6.9
Engineering	35.5	3.4	55.4	3.4	61.3	4.0
Estimating	466.6	44.3	728.0	44.2	814.2	53.3
Other	73.9	7.0	115.2	7.0	132.8	8.7
Support	273.9	26.0	429.8	26.1	546.4	35.8
(Pgm changes)	(726.4)	(68.9)	(1135.4)	(69.0)	(1433.5)	(93.9)
Economic					454.5	29.8
TOT VARIANCE	726.4	68.9	1135.4	69.0	1888.0	123.6
CUR ESTIMATE	1780.0	168.9	2781.6	169.0	3415.2	223.6

SOURCE: March 1982 SAR.

made without reference to a consistent cumulative tabulation. For example, the December 1978 ALCM SAR recorded as "Support" the transfer out of the acquisition program of a quantity of initial spares. In the following year, when these initial spares were reinstated, they were shown as Estimating variance rather than netting them out of Support. In a more complex action, the transfer of a GLCM storage test program from procurement into the development phase was accounted for in the December 1979 GLCM SAR as follows: -$12 million in procurement Estimating variance, +$8.8 million in development Estimating, and +$3.2 million in development Quantity to add four missiles for the test program. When the extended storage program was canceled in the following year, the full value of the program, as given in the June 1981 GLCM SAR, was subtracted from development Quantity variance, leaving the $8.8 million in the cumulative total of Estimating variance. To sort out these anomalies, it is necessary to review the explanations that appear in the SARs at the time the changes are recorded. Even then, the tendency to be obscure or to combine quite different cost drivers into a single sum often prevents a clear understanding of the situation.

Development Cost ($FY77)

Systems development typically has the highest percentage rate of cost growth. Fortunately, this phase only accounts for about 20-30 percent of the total program cost. The ALCM program has experienced a 41 percent cost growth in its development phase. (Although this is an overall average of 7.4 percent per year through the March 1982 SAR cutoff date, the increases before the DSARC III amounted to approximately 11.2 percent annually.) The largest contributor to this growth was the accelerated schedule coupled with some additional requirements imposed during the flyoff. Delays in the flight test schedule, some a result of Congressional direction, added $83 million to the development cost, as given in the Schedule category of the December 1980 and 1981 ALCM SARS. The cost of the flyoff support was underestimated by $6 million, as given in the Estimating category of the December 1978 ALCM SAR. These unexpected cost add-ons required reprogramming of $66 million (in one case from pilot production funds),

to alleviate the shortfall. A redesign of the AGM-86B was made during the flyoff to use casting instead of machining for its four main body tanks.[2] Additional sources of cost increases, as given in the Engineering category of the December 1978, ALCM SAR, include the effort to increase the commonality between the AGM-109 and GLCM/SLCM (although this is expected to result in procurement savings), and ALCM/B-52 integration problems.

The SLCM program development estimate registered a similar amount of cost growth, 39 percent, which is 7.5 percent per year to date. The cost of a one-year delay to improve submarine launch reliability and to increase commonality with the GLCM and AGM-109 was estimated to be $27 million in December 1978 SAR. By recovering test missiles equipped with a REM, the program was able to save $17.5 million for seven missiles. The cost of adding and accelerating development of the conventionally armed land-attack missile variant (December 1979 SAR), and the cost of establishing a follow-on improvement program (December 1981 SAR), were combined in the SAR with other extraneous reasons for cost growth. These two efforts, however, may have been substantial additions to the development cost. Because they are *additional* development tasks, they do not represent cost growth in the negative sense. As discussed below, the cost of developing the conventionally armed land-attack SLCM was not part of the initial DE.

Although the extended gestation period of the SLCM program provided a good basis for the GLCM missile estimate, the SLCM launch system could not be used as a basis for the complex GLCM ground mobile operational concept. The GLCM program development cost increased 231 percent from its original baseline DE due almost entirely to design changes in the launch and peculiar ground support equipment that evolved after the DSARC II development estimate was made. This is equivalent to an average of 44.1 percent annually to date. As discussed below, these cost increases were primarily due to concurrent system definition and development phases, and unanticipated changes in user requirements that occurred long after the DSARC II. As such, they often were beyond the

[2]Although this increased the ALCM development cost, it is expected to produce a considerable reduction in the more important ALCM procurement cost.

control of the JCMPO. Changes in the GLCM *missile* cost were small compared with changes in developmental cost associated with the GLCM Transporter Erector Launcher and Launch Control Center. However, the GLCM development cost would have been even greater if the decision had not been made to rely on the nuclear-armed land-attack SLCM as its air vehicle with only minor modifications. One JCMPO source estimated that the GLCM developmental cost was actually only about one half of what would have been necessary to develop the air vehicle had this common approach not been followed.

Military Construction Cost ($FY77)

Military construction for the SLCM program is negligible. It also is a small item for the ALCM, so its 60 percent growth is fairly unimportant in terms of program cost. The increase is attributed to the cancellation of the limited operational capability and the establishment of an additional bomber base. For the GLCM program, however, the underst tement of the requirements for its ground based mobile system, together with the lack of suitable existing NATO installations for the projected GLCM deployment, led to a 321 percent cost growth of $165 million, almost entirely due to an overestimate by NATO officials of the number of bases that were available, when in reality *none* of these bases were acceptable for GLCM deployment. Consequently, the increase in military construction costs above the baseline DE was necessary to rectify a problem that was also beyond the control of the JCMPO.

Procurement Cost ($FY77)

The greatest cause for cost growth in the procurement phase of the ALCM and SLCM programs was a large increase in their missile buy quantities. The SLCM procurement quantity rose from a baseline estimate of 1082 to 3994 (a 269 percent increase), and its added cost is measured in the billions. The ALCM also registered an increase from 3424 to 4348 missiles (27 percent). The GLCM program was cut from 696 missiles to 560 (a 20 percent decrease) shortly after it entered full scale development; it has remained there ever since.

Total procurement costs are very sensitive to the number of units produced. It would be misleading to compare cost growth ratios of several different programs if some held production quantities constant while others did not, so we have normalized the cost growth figures in the procurement phase to correspond with the original baseline quantities. These are the quantities that underlie their original cost estimates and form the basis of the cost growth ratios.[3]

Figure I.1 tracks the changes in SLCM quantity versus total SLCM program costs, including its three missile variants.[4] At the time of the DSARC II, its Development Estimate was established at a little more than $1 billion for a total of 1082 missiles and associated support equipment. Cost growth of $114 million was recorded at that quantity until in FY 78 the program was cut by 831 missiles and associated support equipment, as indicated in the figure. Additional episodes of

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[3] One source of difficulty in normalizing the SLCM costs to the DE quantity involved the canister and capsule used for ship and submarine launch. The difference in the unit costs of these devices was estimated to be approximately $50,000 (FY77). Consequently, to provide an accurate picture of the SLCM cost growth, normalization to the total DE quantity coupled with the fraction of ship and submarine launched missiles would be necessary. Although we did not include this in our normalization, the resulting error should be small because the cost of the devices represents approximately 7 percent and 5 percent of the SLCM DE air vehicle and total procurement costs, respectively.

[4] Although we could accurately track the anti-ship SLCM quantity and cost through the SAR data, we could do so only for the aggregate of the two land-attack variants (conventionally and nuclear armed) because of insufficient data. Before the December 1979 SLCM SAR, the land-attack missile quantities reported were only for the nuclear-armed version, because the conventionally armed variant was not yet approved. Even though the approved program IOC date for the nuclear-armed variant was given as "to be determined" in the December 1979 SAR and all subsequent issues (through March 1982), there was no indication from the available back-up data that the actual procurement quantity was zero. In the three calendar quarters where some additional information was available (December 1980 and March and December 1981), the quantity of conventionally armed variants was substantially greater than for the nuclear-armed versions. Although the addition of DSMAC and airframe modifications to the conventionally armed variant should increase its cost, that increase should be counterbalanced by learning curve effects of greater air vehicle procurement quantity. Consequently, the cost difference between the two land-attack SLCM variants was believed to be small, and failure to compensate for it should have introduced only a minor error in our analysis.

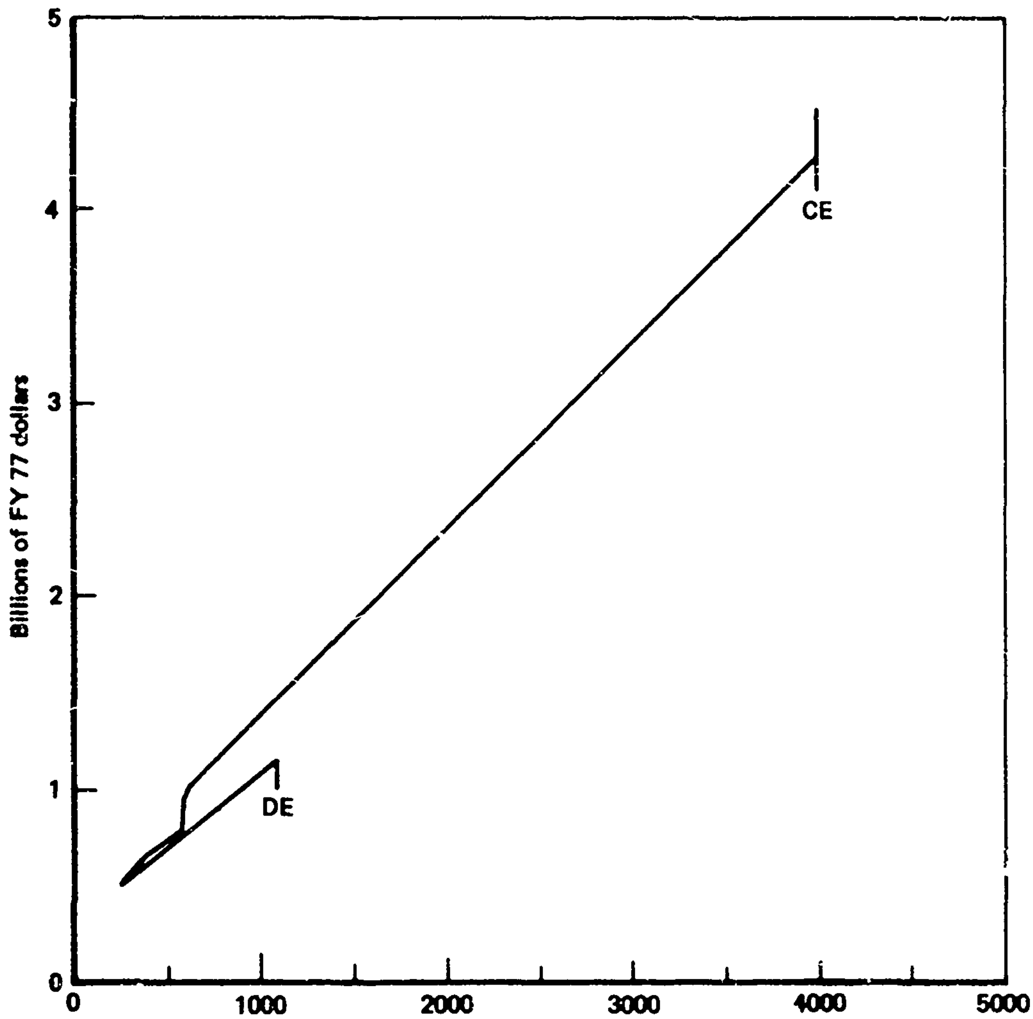

Fig. I.1 -- SLCM Procurement Cost-Quantity Changes

cost growth and incremental quantity increases occurred in the following years. The number of launch platform types also increased from three to 10, causing a large increase in the cost of launch equipment and peculiar support equipment that was not envisioned at the time of the DSARC II.

To properly normalize these costs in terms of the DE quantity, we must do more than disregard the pluses and minuses generated by the quantity changes. The large cost changes that occurred at the 3994 missile quantity obviously overstate what the cost of these changes would have been for the baseline quantity of 1082, and in this analysis

they were scaled down accordingly. Figure I.2 shows the less complex quantity change patterns of the ALCM and GLCM missiles, versus their total program costs. They reflect the Air Force's style of programming the entire anticipated buy at the time of DSARC II, with only some overall final adjustments as the program nears completion. The ALCM and GLCM program costs also had to be normalized to represent their baseline quantities; 3424 missiles in the case of the ALCM and 696 missiles for the GLCM.

The calculations for the normalization process for these three weapon systems are illustrated in Tables I.4, I.5, and I.6. Using the ALCM program as an illustration (Table I.4), the magnitude of the quantity changes and the total quantities at which the other cost growth occurred are indicated in the procurement quantity column. The

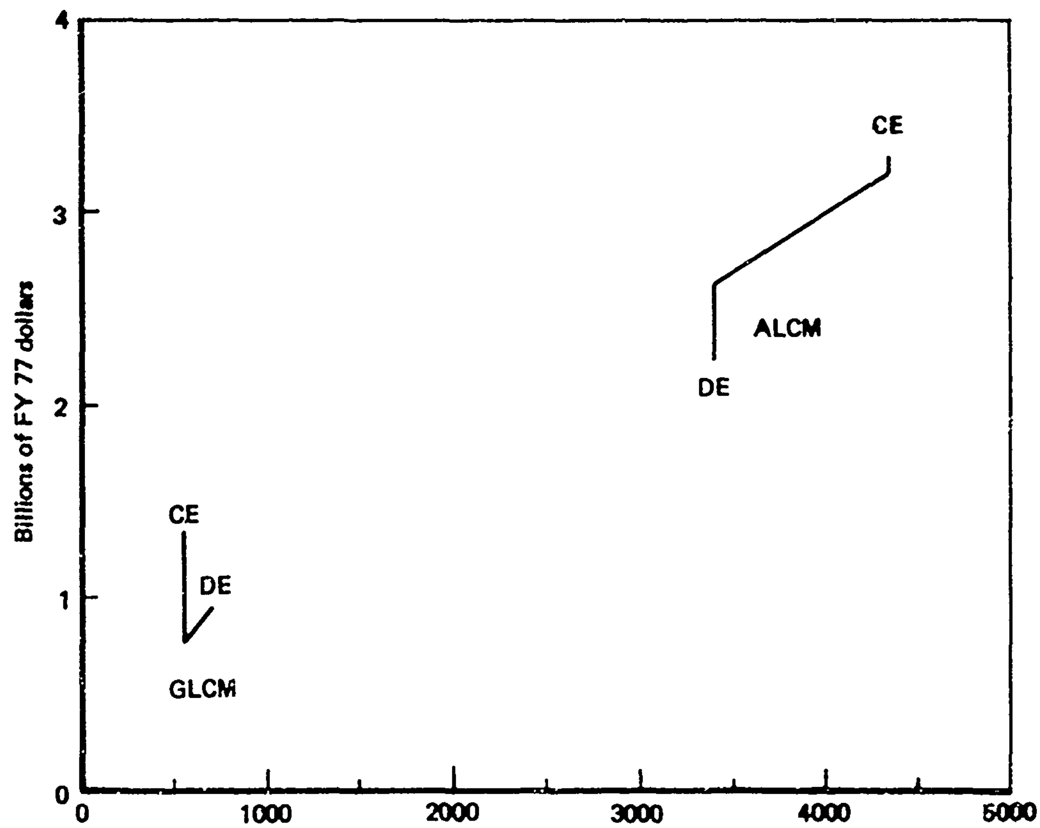

Fig. I.2 -- ALCM and GLCM Procurement Cost-Quantity Changes

Table 1.4

ALCM COST GROWTH, BY YEAR, PROGRAM COSTS NORMALIZED FOR DE BASELINE QUANTITY OF 3,424 PROCUREMENT MISSILES(a)
(Costs in millions of base year (FY77) dollars)

SAR Date	Procure Qty	Total proc Cost	Procurement Cost Change: Quantity: Maj Eq	Procurement Cost Change: Quantity: Suppt	Procurement Cost Change: Other Proc	Other Procurement (Normalized) (b): Missile	Other Procurement (Normalized) (b): Support	Other Procurement (Normalized) (b): Total	Total Dev Cost	Total Mil Const Cost	Total Pgm Cost
(DE)	3424	2311.6				2094.4	217.2	2311.6	696.1	121.4	3129.1
Dec77 CE	3424	2311.6				2094.4	217.2	2311.6	696.1	121.4	3129.1
CE/DE						1.00	1.00	1.00	1.00	1.00	1.00
	-6	-8.7	-8.7								
	@3418	-61.5			-61.5	-92.8	+31.2	-61.6	+142.9	-31.0	+50.3
Dec78 CE	3418	2241.4				2001.6	248.4	2250.0	839.0	90.4	3179.4
CE/DE						.96	1.14	.97	1.21	.74	1.02
	@3418	-5.4			-5.4	- 28.8	+23.4	-5.4	+71.9	+32.8	+99.3
Dec79 CE	3418	2236.0				1972.8	271.8	2244.6	910.9	123.2	3278.7
CE/DE						.94	1.25	.97	1.31	1.01	1.05
	@3418	+232.2			+232.2	+213.0	+19.6	+232.6	+26.8	+34.9	+294.3
Dec80 CE	3418	2468.2				2185.8	291.4	2477.2	937.7	158.1	3573.0
CE/DE						1.04	1.34	1.07	1.35	1.30	1.14
	@3418	+150.8			+150.8	+87.6	+63.5	+151.1			+151.1
	+930	+588.8	+552.2	+36.6							
	@4348	+61.0			+61.0	+43.9	+4.1	+48.0	+48.5	+39.8	+136.3
Dec81 CE	4348	3268.8				2317.3	359.0	2676.3	986.2	197.9	3860.4
CE/DE						1.11	1.65	1.16	1.42	1.63	1.23
	@4348	-9.0			-9.0		-7.1	-7.1	-4.2	-3.8	-15.1
Mar82 CE	4349	3259.8				2317.3	351.9	2669.2	982.0	194.1	3845.3
CE/DE						1.11	1.62	1.15	1.41	1.60	1.23
Avg Annual Change(%)						2.03	11.81	2.95	7.82	11.41	4.36

(a) Based on SAR Variance data.

(b) Procurement cost changes not related to changes in quantity were normalized on the basis of the ratio between the DE baseline quantity and the CE quantity--CE cost(DE qty/CE qty).

procurement costs, as recorded in the SARs, are shown in the columns entitled "Total" and "Procurement Cost Change." They sum the cost changes that are attributed both to the quantity changes and to other reasons such as schedule, engineering, and estimating. The normalized estimates of the procurement cost growth, which form the basis of our cost growth ratios, appear to the right of the SAR figures. In this adjustment process, the direct cost changes attributed to changes in quantity were excluded. The remaining procurement cost changes were distributed by equipment category and then scaled according to the percentage difference between the missile baseline quantity and the quantity assumed in each of the cost change estimates.[5]

Change in missile quantity also was used as a proxy for normalizing support equipment cost variances. Stockpiling beyond the basic load is presumed to be minimal, so a strong correlation should exist between missile quantities and support requirements.

An effort was made to determine appropriate cost curve slopes and cost curve segments to normalize the cost changes, taking into account the procurement quantities and degree of commonality of the other cruise missile systems. This difficult exercise proved unnecessary in view of the large combined quantities involved and the low rates of learning implied by missile and support equipment cost curve slopes. Most of the marginal quantity changes occurred where the slopes of these cost curves approached unity; therefore, in the interest of simplicity we used the more direct scaling method, recognizing that cost changes following very large quantity changes would tend to be undercorrected. Adding the normalized procurement costs to the total costs of development and military construction result in the total normalized program cost estimates tracked in Figs. I.1 and I.2. The cost growth ratios shown in the tables indicate the growth experienced in each of the cost categories as well as the overall program total.

Similar data for the SLCM and GLCM programs are shown in Tables I.5 and I.6, respectively. When the quantity of SLCMs decreased drastically in 1978, the December 1979 GLCM SAR attributed a 15 percent increase in

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[5] Normalized cost change = [total CE cost change] times [(DE quantity)/(CE quantity)].

Table I.5

GLCM COST GROWTH, BY YEAR. PROGRAM COSTS NORMALIZED FOR DE BASELINE QUANTITY OF 696 PROCUREMENT MISSILES(a)
(Costs in millions of base year (FY77) dollars)

SAR Date	Pro-cure Qty	Total Proc Cost	Procurement Cost Change: Quantity: Maj Eq	Quantity: Suppt	Other Proc	Other Procurement (Normalized) (b): Missile	Launch Eq.	Other Suppt	Total	Total Dev Cost	Total Mil Const Cost	Total Pgm Cost
(DE)	696	927.6				646.9	131.8	148.9	927.6	74.8	51.2	1053.6
Dec77 CE	696	927.6				646.9	131.8	148.9	927.6	74.8	51.2	1053.6
CE/DE						1.00	1.00	1.00	1.00	1.00	1.00	1.00
	@696	+1.6			+1.6	-80.1	+62.9	+18.8	+1.6	+60.0	-6.2	+55.4
Dec78 CE	696	929.2				566.8	194.7	167.7	929.2	134.8	45.0	1109.0
CE/DE						.88	1.48	1.13	1.00	1.80	.88	1.05
	-136	-131.9	-131.9									
	@560	+156.1			+156.1	+47.2	+148.4	-1.6	+194.0	+28.1	-16.9	+205.2
Dec79 CE	560	953.4				614.0	343.1	166.1	1123.2	162.9	28.1	1314.2
CE/DE						.95	2.60	1.12	1.21	2.18	.55	1.25
	@560	+166.2			+166.2	+85.8	+21.9	+98.9	+206.6	+10.0	+97.6	+314.2
Dec80 CE	560	1119.6				699.8	365.0	265.0	1329.8	172.9	125.7	1628.4
CE/DE						1.08	2.77	1.78	1.43	2.31	2.46	1.55
	(c)	+7.2	+7.2									
	@560	+189.5			+189.5	-143.9	+364.6	+14.8	+235.5	75.0	+90.1	+400.6
Dec81 CE	560	1316.3				555.9	729.6	279.8	1565.3	247.9	215.8	2029.0
CE/DE						.86	5.54	1.88	1.69	3.31	4.21	1.93
Mar82 CE	560	1316.3				555.9	729.6	279.8	1565.3	247.9	215.8	2029.0
CE/DE						.86	5.54	1.88	1.69	3.31	4.21	1.93
Avg Annual Change(%)						-2.68	86.39	16.75	13.09	44.08	61.24	17.63

(a) Based on SAR Variance data.

(b) Procurement cost changes not related to changes in quantity were normalized on the basis of the ratio between the DE baseline quantity and CE quantity--CE cost(DE qty/CE qty).

(c) Additional launch equipment.

Table 1.6

SLCM COST GROWTH, BY YEAR, PROGRAM COSTS NORMALIZED FOR DE BASELINE QUANTITY OF 1,082 PROCUREMENT MISSILES (502 ANTI-SHIP AND 580 LAND ATTACK MISSILES)(a)
(Costs in millions of base year (FY77) dollars)

			Procurement Cost Change			Other Procurement (Normalized)(b)							
			Quantity			Missiles							
SAR Date	Procure Qty	Total Proc Cost	Maj Eq	Suppt	Other Proc	Anti-Ship	Land Attack	Launch Eq.	Other Suppt	Total	Total Dev Cost	Total Mil Const Cost	Total Pgm Cost
(DE)	1082	1023.6				363.3	422.7	90.2	147.4	1023.6	782.8	0.0	1806.4
Dec77 CE	1082	1023.6				363.3	422.7	90.2	147.4	1023.6	782.8	0.0	1806.4
CE/DE						1.00	1.00	1.00	1.00	1.00	1.00	---	1.00
	@1082	+114.0			+114.0			+114.0		+114.0			+114.0
	-831(c)	-741.7	-634.4	-107.3									
	Q251	+27.6			+27.6	+11.0	+12.7	+50.5	+44.8	+119.0	+20.9	+0.4	+140.3
Dec78 CE	251	423.5				374.3	435.4	254.7	192.2	1256.6	803.7	0.4	2060.7
CE/DE						1.03	1.03	2.82	1.30	1.23	1.03	---	1.14
	+188(d)	+210.0	+141.1	+68.9									
	@439										+99.0	-0.1	+98.9
Dec79 CE	439	633.5				374.3	435.4	254.7	192.2	1256.6	902.7	0.3	2159.6
CE/DE						1.03	1.03	2.82	1.30	1.23	1.15	---	1.20
	+135(e)	+87.6	+87.6										
	@574	+226.2			+226.2	+78.8	+91.2	+118.6	+137.8	+426.4	24.0		+450.4
Dec80 CE	574	947.3				453.1	526.6	373.3	330.0	1683.0	926.7	0.3	2610.0
CE/DE						1.25	1.25	4.14	2.24	1.64	1.18	---	1.44
	+70(f)	+58.1	+58.1										
	@644	+31.0			+31.0	-21.0	-24.2	-42.5	+139.8	+52.1			+52.1
	+3350(g)	+3230.5	+2988.6	+241.9									
	@3994	+255.9			+255.9	-16.0	-18.5	+103.8		+69.3	+162.0		+231.3
Dec81 CE	3994	4522.8				416.1	483.9	434.6	469.8	1804.4	1088.7	0.3	2893.4
CE/DE						1.15	1.14	4.82	3.19	1.76	1.39	---	1.60
	@3994	-394.4			-394.4			-106.8		-106.8	+1.7		-105.1
Mar82 CE	3994	4128.4				416.1	483.9	327.8	469.8	1697.6	1090.4	0.3	2788.3
CE/DE						1.15	1.14	3.63	3.19	1.66	1.39	---	1.54
Avg annual change (%)						2.77	2.76	50.17	41.66	12.54	7.48	---	10.35

(a) Based on SAR Variance data.

(b) Procurement cost changes not related to changes in quantity were normalized on the basis of the ratio between the baseline DE quantity and CE quantity--CE cost(DE qty/CE qty).

(c) -251 anti-ship; -580 land attack.

(d) -8 anti-ship; +196 land attack.

(e) -66 anti-ship; +201 land attack.

(f) +24 anti-ship; +46 land attack.

(g) +392 anti-ship; +2,958 land attack.

GLCM costs, amounting to $91 million, to the SLCM quantity reduction. Conversely, between the December 1980 and December 1981 SARs, when the GLCM procurement quantity was constant and total cruise missile procurement quantity increased by approximately a factor of 6, the GLCM unit cost, as well as the SLCM unit cost, considerably decreased.[6] The December 1980 normalized missile cost data shown in Tables 1.5 and I.6 yield a land-attack SLCM unit cost of $.91 million, and a GLCM unit cost of $1.01 million. The December 1981 SAR data indicate that the land-attack SLCM unit cost decreased to $.83 million, while the GLCM unit cost decreased to $.80 million (all in $FY77). Presumably, a part of this GLCM cost reduction was due to learning curve effects for the common missile components and a more efficient production rate, although this was not acknowledged in the GLCM SAR.[7] The lack of a similar decrease in ALCM costs suggests offsetting cost growth in its airframe, the only major subsystem that is not common to the other land-attack cruise missiles. The JCMPO staff expects that the recently enacted AUR competition between GD/C and MDAC to produce complete GLCM, SLCM, and MRASM air vehicles should result in further cruise missile cost reductions for these variants.

External Factors That Increased Cruise Missile Weapon System Costs

Some of the cost growth observed in the above discussion was caused by factors external to the cruise missile program. One major source of cruise missile program cost variations was the pressure brought on the JCMPO by the services, Congress, OSD, and the President. The B-1A production cancellation and SALT II influenced the cruise missile programs, as did a myriad of changing user requirements. A brief

[6] Some of the SLCM cost reduction is attributed to a downward revision in an earlier estimate of the effect of inflation on current production costs (December 1981 SAR).

[7] Another source of procurement cost reduction for the GLCM and the ship-launched SLCMs was the elimination of the water tight shroud and associated hardware. Although no documentation or related information could be found in the SAR, one JCMPO source estimated that this equipment had a unit cost of approximately $50,000 (FY77), and that cost savings from this change were factored into the SAR data before our March 1982 SAR cutoff date.

discussion of how these factors affected the ALCM, GLCM, and SLCM programs is thus germane.

In the GLCM program, user requirements expanded after the start of full scale development. This, combined with the considerably more complicated operational concept and increased hardware sophistication that occurred after the DSARC II, led to large program cost growth. From the January 14, 1977, DSARC II decision memorandum establishing the GLCM program through an AFSARC II held in January 1979, the GLCM operational concept changed considerably. Although the AFSARC II crystallized much of the operational concept and hence the required hardware, additional program instability resulted from the subsequent NATO debate on GLCM deployment. The NATO High Level Group decision to deploy GLCM was made in December 1979, but the program cost changes continued.

The GLCM weapon system presented at DSARC II (held in January 1977) featured a fairly simple launch module consisting of a single tractor containing the launch control equipment, and a trailer that carried the launcher for four cruise missiles. The current concept consists of two Launch Control Centers (LCCs), four Transporter Erector Launchers, and four GLCMs per launcher. Furthermore, the LCCs are self-sustained facilities that provide protection for the operators against potential biological, chemical, radiological, and small arms threats. In addition, the LCCs are cross-wired so that either LCC can launch any of the 16 missiles with minimal delay. Although perhaps necessary for tactical nuclear applications, these added requirements greatly increased the cost of the GLCM launch equipment.

The SLCM project also experienced system refinements that occurred after the DSARC II and that were beyond the control of the JCMPO. Much of the evolution in support requirements that resulted was essential to ensure that the SLCM could be effectively used in the fleet by having accurate target acquisition data and adequate launch equipment. Furthermore, only the nuclear armed land-attack and anti-ship SLCMs were approved in the January 14, 1977, DSARC II decision memorandum. The conventionally armed land-attack SLCM was not officially considered as part of the SLCM program until 1978* and, hence, was not included in the

* It was first reported in the December 1979 SLCM SAR.

baseline DE. In addition, the number of SLCM launch platforms increased considerably during this time as a result of changing Navy, OSD, Congressional, and Presidential priorities pertaining to the SLCM. The two submarine and one ship classes initially designated at the DSARC II rose to three submarine and seven ship classes. This expansion led to a considerably greater total requirement for SLCM launch equipment (e.g., mission planning and targeting equipment) and peculiar support equipment than was anticipated at DSARC II. There also were large fluctuations in the total number of SLCMs programmed for acquisition during this period. These, coupled with numerous externally-directed SLCM schedule changes, contributed to SLCM development and procurement cost growth.

In the ALCM program, two factors led to development cost increases that were beyond the control of the JCMPO. First, the January 14, 1977, DSARC II decision memorandum gave the long-range ALCM priority over the existing short range model. The extended range ALCM-B was only a paper design at that time.[9] In addition, before that time only the AGM-86A had been flight tested and it was receiving most (if not all) of the missile developmental funding. Consequently, the AGM-86B represented a considerable design change from the AGM-86A, which was the principal missile design presented at DSARC II. This contributed to the increase in ALCM development program cost. Also, the competitive flyoff between the AGM-86B and the AGM-109 (formally directed by Dr. William Perry on September 30, 1977) accelerated the development of the AGM-86B and contributed to the development program cost growth. Both the AGM-86B and the AGM-109 were carried through full scale development before selection of the AGM-86B as the ALCM, less than one month before the DSARC III. Obviously, this too led to a cost increase in the ALCM development program that could not have been anticipated at the DSARC II.

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[9] A second long range ALCM, known as the "class II vehicle," was also briefed at the DSARC II review. It was basically an ALCM-A with an extended fuel tank. That vehicle had also undergone only a limited development before the DSARC II and was not approved for full scale development.

DMA CRUISE MISSILE SUPPORT COSTS

The cost of generating data for cruise missile terrain following and TERCOM is a small, but not insignificant, element of the overall joint cruise missiles program cost. That cost, however, was incurred by DMA and is not reported as a JCMPO expenditure.

All DMA products are individually programmed for each fiscal year. The DMA production program, which is based upon user requirements, is submitted yearly in the normal budget cycle. Additional funding has been provided as program requirements have been refined or changed. Similarly, support funding for Testing and Evaluation (T&E) is reported under a separate line used to support all T&E. This funding is based on a DMA estimate of what will be needed to support T&E of *all* weapon systems. These methods of funding have not varied throughout the support provided to the JCMPO.

A summary of actual DMA cruise missile support costs from FY78-FY83 is given in Table I.7.[10] DTED and VOD directly support cruise missile terrain following; validation represents quality assurance/control for the terrain following and TERCOM data products; and control represents the process of incorporating source data into a unified geodetic network. In addition to the FY78-FY83 data presented in Table I.7, DMA projections for FY84-FY90 are in the range of $30-40 million per year. The DTED, control, VOD, TERCOM, and validation cost data given in Table I-7 include a multiplier of 1.9 against direct labor, so that total labor costs can be portrayed (i.e., raw direct labor, plus leave, training, and supervision). The data for equipment and construction does not contain such a multiplier.

The actual FY78-FY83 and projected FY84-FY90 total cost estimate is considerably higher than those advanced during the earlier stages of the cruise missile program. Differences between earlier and currently projected total data base costs are the result of a number of factors. These include an expansion of area requirements due to increased theater commander interest as the GLCM and conventionally armed land-attack SLCM were introduced, the lack of production experience at the time of the

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[10] All costs shown in this section are in FY82 dollars unless otherwise noted.

Table I.7

DMA CRUISE MISSILE SUPPORT COST SUMMARY

Item	FY78	FY79	FY80	FY81	FY82	FY83	TOTAL
DTED	3.6	6.5	10.8	12.1	12.3	14.3	59.6
Control	.9	.9	1.3	1.7	3.6	4.6	13.0
VOD	0	0	0	3.8	4.6	3.4	11.8
TERCOM	0	5.9	6.5	5.1	5.1	4.8	27.4
Validation	.4	.9	.4	1.0	.7	.9	4.3
Equipment	0	8.8	0	1.9	1.3	8.2	20.2
Construction	0	1.6	0	0	0	25.1	26.7
TOTAL	4.9	24.6	19.0	25.6	27.6	61.3	163.0

initial estimates, the delay in the approval of the use of an alternative TERCOM source data form, shifts in user area priorities, the lack of usable preferred source material in some areas, the accelerated production required by late requirement identification, and a change in the ratio of TERCOM map types (the number of landfall versus enroute versus terminal maps). Similarly, the approved yearly production schedule rates for the early years consistently fell below original estimates, particularly for TERCOM. This was a consequence of the same factors that led to increased program cost. The FY81-FY86 production program is, at the time of this writing, back in phase and production rates are meeting or exceeding the original predicted schedule.

Projected DTED expenditures for FY84-FY90 are estimated to be similar to those for FY81-FY83 ($12-14 million annually). The exact DTED expenditures through FY86 will be influenced by the need to update the DTED coverage with data generated from more accurate sources. During FY87-FY90, expenditures may be necessary to produce DTED for new

targeting areas. Because both quantitative and qualitative VOD requirements were slow to be defined, DMA diverted resources from that program to other high priority programs during FY82 and FY83, thus the decreased support cost over that period. Since efforts are still underway to better define the VOD quantitative requirement, confident expenditure projections cannot be made for FY84-FY90; however, a requirement for these types of data will remain as a cruise missile support cost. TERCOM, control, and validation expenditures are expected to remain at approximately the $5, $3-5, and $1 million levels, respectively, from FY84-FY90.

Variations in the projected expenditures for DMA cruise missile support may result if user mission requirements change (e.g., if additional mission areas are identified where the data bases do not exist, they will have to be created). The MRASM, with a potential for wide area deployment, could also increase this cost.

From the data given in Table I.7 for FY78-FY83, and projections of $30-40 million per year for FY84-FY90, the estimated total cost of the DMA cruise missile support is between $373 million and $443 million. A simple analysis was performed to estimate individual category costs for DMA cruise missile support through FY90 based upon existing data for FY78-FY83, and an estimated total program cost of $30 million to $40 million for FY84-FY90. Average DTED, TERCOM, and validation costs were determined over the FY81-FY83 period. The average control and equipment and construction costs were estimated from FY81-FY82 and FY78-FY83 data respectively, while an average VOD cost of $2 million per year was selected for the FY84-FY90 period. The total yearly DMA cruise missile support cost projected for the FY84-FY90 period was $32.7 million (FY82), which fell within the DMA estimate range of $30 to $40 million per year. The individual category costs were then rescaled to the DMA bounds of $30 million and $40 million using a multiplier of .92 (30/32.7) and 1.22 (40/32.7), respectively.

From this, total estimates based upon actual FY78-FY83 and projected FY84-FY90 data were derived for each category and are presented in Table I.8. From the data given in Table I-8, the total estimated non-equipment and construction data costs range between $276 million and $328 million for DMA cruise missile support. The single

Table I.8

APPROXIMATE DMA CRUISE MISSILE COST BY CATEGORY

Item	Cost[a]	Cost[b]
DTED	142	170
Control	39	47
VOD	24	29
TERCOM	60	70
Validation	10	12
Equipment	42	49
Construction	55	65
	---	---
TOTAL[c]	373	443

[a] Based upon FY78-FY83 actuals and a projected $30 million per year total support cost (FY82) for FY84-FY90

[b] Based upon FY78-FY83 actuals and a projected $40 millionper year total support cost (FY82) for FY84-FY90

[c] The totals do not sum exactly to $373 and $443 million because of rounding errors.

most expensive DMA cruise missile support product is DTED, which is approximately 2.6 times the TERCOM cost. It should be recognized, however, that the DTED supports a wide variety of weapon systems in addition to cruise missiles (e.g., aircraft simulators, Pershing II, terrain masking studies, and electromagnetic propogation computations).

Initially, DTED was funded to support programs other than the cruise missile (e.g., flight simulators), and as such would be provided "free" to the cruise missile program. Later, however, the cruise missile program was used to justify funding for DTED production acceleration and data base maintenance. Additional resources were also required because of a major shift in user area priorities. In the case of TERCOM, however, funding was required directly in support of the cruise missile program because this data form is not currently in use by other programs, although TERCOM is under consideration as a guidance updating system for several weapon systems under development (e.g., maneuvering reentry vehicles).

The $70 million to $80 million estimated range for TERCOM is substantially less than the estimates of Baker ($165 million)[11] and Toomay ($1 billion).[12] Although the total estimated DMA cruise missile support cost range of $373 million to $443 million is not an insignificant sum, it represents only a few percent of the total procurement cost of the first generation cruise missile system. It should be pointed out, however, that both DMA's historical costs and their projections are based on requirements for the nuclear-armed land-attack cruise missiles (ALCM, GLCM, and SLCM) and only minimal conventionally armed land-attack requirements. As targeting and employment concepts for the conventionally armed land-attack cruise missiles (MRASM and SLCM) become better defined, and should they include large Third World options, the DMA support costs could go up considerably and become a much greater portion of DMA total system costs.

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[11] John C. Baker, "Program Costs and Comparison," in *Cruise Missiles*, The Brookings Institution, Washington, D.C., 1981, p. 105.

[12] John C. Toomay, "Technical Characteristics," ibid.